

An Object-Relational Prototype of a GIS-Based Disaster Database

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of Master of Applied Science

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement data of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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ABSTRACT

Each year, natural disasters cause billions of dollars of property and infrastructure damage, unscheduled disruption to socio-economic activities and tragic loss of human lives. The importance of collecting and maintaining detailed and accurate records on disastrous events for an effective risk assessment and disaster mitigation has been widely recognised. Historical data to which risk assessors refer are composed primarily of disaster event histories listed with aggregated attributes. Recently adopted information-age concepts and tools offer scope to build integrated databases and support database upgrade by facilitating data integration. Considerable efforts have been directed towards the establishment of databases on historic disasters but many disaster databases built containing primarily a set of historical disaster events with aggregated attributes.

Disaster phenomena vary dramatically with both space and time. It is therefore important to deploy a database that integrates spatial-temporal dimensions of disaster events so that efficiency in interactive query and reporting is supported. It is also important to make such a database readily accessible to a variety of users from government agencies, non-government organisations, research institutes and local communities, so that emergency response, impact and risk assessment, and mitigation planning can be effective and efficient in information-age terms.

This thesis presents a study that investigates the current scope deployment of a effective and efficient geographical information system (GIS) based approach to the representation, organisation and access of disaster information. Included are logical data models for representing disastrous events, the object-relational approach to database implementation, and the scope to deploy internet-based user-interface for database queries and report generation. Key aspects of a disaster event, including the spatial-temporal dimensions of the hazard and its impacts, are considered in the development of data models and database implementation in order that user-friendly querying and reporting operations be supported. The technological strengths of GIS, database management systems, and Internet-related toolboxes are leveraged for developing a prototype of a GIS-based, object-relational disaster database with an Internet-based user interface that supports multi-mode (including map-based) database queries and flexible facilities

for report generation. The prototype was built to support data query and modelling for and by stakeholders living with flood hazard within Gardiners catchment, Melbourne, Australia. It is shown that adaptation of the approach exemplified in this study would be constrained by the fact that much of the necessary archival data is unfit for use in the kind of integrated spatial modelling that emergency managers could call for.

Key word: disaster event, object-relational data model, GIS, impact and risk assessment

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1 INTRODUCTION

1.1. Realities

Recent devastating events, such as the Indian Ocean tsunami in 2005 and the Haiti Earthquake in 2010, have made us all acutely aware of the vulnerability of our modern society to and the great impacts of, natural disasters. Each year, natural disasters cause billions of dollars of property and infrastructure damage, unexpected disruption to socio-economic activities and tragic loss of human lives globally (Mauch and Pfister, 2009, Gott, 2009, Srinivas and Nakagawa, 2008, Abbott, 2009). In Australia, the damage caused by recent natural disasters is more than \$1.14 billion (Commonwealth of Australia, 2002). Effective mitigation of natural disaster impacts has become increasingly critical and crucial to our society (Wang and Cheng, 2008, Srinivas and Nakagawa, 2008, Carrara and Guzzetti, 1995, Oosterom et al., 2005, Li et al., 2007a, Alcantara-Ayala, 2002, Prestipino, 2004). Concern ranges from government to the general public, from local communities to individuals, from business companies to non-government organisations (NGOs). Among them all, more and more attentions is being drawn to natural disasters and their related issues (Johnson et al., 1997, Zhang et al., 2003, Mauch and Pfister, 2009, Karimi and Hüllermeier, 2007, Waring et al., 2005, Pelling, 2003).

To reduce disaster impacts and achieve safer and more sustainable communities, the importance of proper understanding and management of disaster events has been widely recognised (Amin and Goldstein, 2008, Oosterom et al., 2005). Knowing where and when the natural disasters have occurred and the nature of their impacts is essential for understanding disasters and planning for damage reduction (Liu, 2005). It is particularly important to take the vulnerability of human populations into consideration. Critical infrastructures, and other spatially distributed phenomena are relevant to response and recovery (Liu, 2005) and emergency managers need on-demand access to information about them. In recent years, many digital geospatial technologies, such as remote sensing, geographic information systems (GIS), the Global Positioning System (GPS), remote sensing and photogrammetry have experienced significant recognition as decision support tools. As a result, great benefits have been generated in all aspects of disaster management (from preparedness, prevention, and protection through detection to response and

eventual recovery) where and when information on natural disasters can be timely acquired, properly interpreted, and effectively disseminated (Goodchild, 2006).

When disasters strike, many parties (including government agencies, fire, medical and police departments, Red Cross and other relevant NGOs, insurance and utility companies) will be involved immediately. Much depends on the extant status of the huge volume of data (including datasets on road and utility networks; hospitals, fire stations, medical emergency stations and other types of buildings; damaged areas and damaged facilities) that could be called on by the emergency managers. It will have been collected and updated by different organisations for supporting disaster response operations (Mansourian et al., 2006). However, without a concerted arrangement, both duplications in data collection and gaps in collected data content and coverage cannot be avoided. Data duplication normally costs much in terms of human and material resources, time and effort. Data gaps often render many derived information products less useful or even impossible to derive. Some of these could be critical information products. Datasets compiled by different organisations are often different in terms of resolutions (spatial, temporal, and thematic), precision, accuracy, completeness and semantics. This is due to varying requirements of applications and different interests and emphases (Chad, 2002, Devin et al., 1983, Greene, 2001, Plewe, 1997). Therefore, sharing of information (under proper guidelines) about natural disasters is crucial and beneficial for all stakeholders even though very different needs may be present among them (Masser et al., 1996, Sieber, 2006). If a framework of collecting, maintaining, accessing and reporting data on natural disasters, with clearly defined responsibilities and data standards, can be established among all stakeholders involved, the efforts for mitigating the impacts of natural disasters can be better facilitated. The collaborative and coordinative effort should lead to an easy access of comprehensive natural disaster information in a shorter time and with much less effort. The result could be of enormous benefit to both the stakeholders and the general public.

1.2. Challenges

However, sharing information on natural disasters is difficult. Natural disasters refer to dynamic and complex processes that vary dramatically with both space and time. Proper representation of disaster events in both space and time is the first challenge (Monica, 1999, Yuan, 1996). Timely

and accurate data collection on the distributive and dynamic impact of natural disasters is the second challenge, not only because datasets on the events are very evaporative due to fast changing situation, also because the multifaceted nature of the situation demands a well coordinated multidisciplinary efforts which may not be easy to organize, especially during an emergency. Disaster impacts can be measured in many different ways (e.g. in terms of impacts on human, social and economic capital) and typically represented by stock variables such as population, built property and public infrastructure, livestock, agricultural land, etc (Patwardhan and Sharma, 2005). The third challenge is how to reliably assess the impacts and estimate the damage and loss of a natural disaster event (Patwardhan and Sharma, 2005, Waring et al., 2005). Information on natural disasters is not only multifaceted but also voluminous. Another practical challenge is how to store, update and retrieve the data efficiently across different user groups from different disciplines and organisations at different locations. In order to achieve effective and efficient sharing of information on natural disasters, research effort has to be focused on the representation, organisation and access of information on natural disasters (Chen, 2004).

In the past decade, considerable research efforts have been directed towards the establishment of databases on disasters (Gott, 2009, Liu, 2005, Prestipino, 2004, Wang and Cheng, 2008, Johnson et al., 1997). As a result, many disaster databases have been built (Goodchild, 2006, Patwardhan and Sharma, 2005, Wang and Cheng, 2008, Zhang et al., 2003). However, most of these databases are primarily a set of lists of disaster events with very limited support for spatial querying and reporting operations (Liu, 2005). Databases of disasters should be an integral part of the important knowledge base of disasters, disaster impacts and disaster scenarios. Spatial data is regarded as a requisite and crucial component of disaster information systems (Amin and Goldstein, 2008). Spatial data is efficient in specifying the location and geographic boundary of a disaster, and enables effective and efficient information sharing on disaster situations (Liu, 2005, Marc et al., 2005, Nooan and Ebooks Corporation., 2008). Besides the spatial dimension, the temporal aspect is also an indispensable and essential component for disaster information that must be integrated into the disaster information management systems (Goodchild, 2006). Hence, both spatial and temporal aspects of disaster events should be represented, and the capability of efficient and interactive temporal-, spatial- and attribute-oriented queries should be supported in a disaster database for emergency response to, and assessing the impacts of, disaster events (Liu, 2005). It is important not only to integrate spatial-temporal dimensions of

disaster events in a disaster database but also to make such a database readily accessible to a variety of users from government agencies, non-government organisations, research institutes and local communities (Greene, 2000, Jensen et al., 2007, Khanal, 2006).

1.3. Objectives

The importance of collecting and maintaining timely and accurate records on disastrous events for effective disaster management is widely recognised (Amin and Goldstein, 2008, Carrara and Guzzetti, 1995, Goodchild, 2006). Geographic information and the technologies that acquire, interpret, and disseminate such information are essential in all aspects of disaster management, from mitigation, preparedness, and detection to response and eventual recovery (Goodchild, 2006, Bennett, 1997).

The main objectives of this research are the representation, organisation, access, and reporting of information on disastrous events, from perspectives of both emergency management and spatial database development. From the emergency management perspective, the prototype disaster database developed in this study, is expected to be useful to better our understanding of current disaster risks, the effectiveness of past disaster mitigation efforts, and future scenarios or trend of disaster impacts. From the spatial database development perspective, the study will evaluate approaches to spatio-temporal data representation and object-relational database implementation.

Managing time with an event-oriented approach is regarded as the most appropriate method for incorporating time into current GIS environment (Claramunt and Bin, 2001). Disaster events are complicated dynamic geographic processes occurring in both temporal and spatial dimensions (Worboys et al., 1990). This study will test this event-oriented approach. The GIS-based object-relational prototype of disaster databases to be developed in this study will explore suitable logical data models for representing the spatial-temporal aspects of disaster events, by taking advantages of both the event-oriented data representation and the object-relational database model (Kovacs and van Bommel, 1998, Larue et al., 1993).

To facilitate efficient access to information on disastrous events by a wide range of users, such as those from government and non-government agencies, research institutes and local communities, both the logical data model and internet-based user interface need to be implemented properly. The data model should incorporate the spatial-temporal aspects of an event, and the user interface should support flexible database queries and report generation (Drummond, 2007, Peuquet and Duan, 1995).

Key aspects of a disaster event, including the spatio-temporal dimensions of the hazard and its impacts, are considered in the development of suitable data representation and database model for supporting user-friendly querying and reporting generation. The technological strengths of GIS (e.g. ArcGIS), DBMS (e.g. ArcSDE and Oracle Spatial), and Internet-related toolbox (e.g. ArcGIS Server) are leveraged for developing a prototype of a GIS-based, object-relational disaster database with an internet-based user interface (developed with XML and JavaScript) to support multi-mode (including map-based) database queries and flexible facilities for report generation (Allen, 2009). Based on these discussions, the key research questions have been identified: 1) How to properly represent disaster events in both space and time dimensions. 2) How to enable information sharing among stakeholders on natural disasters and achieve timely and accurate data access. 3) How to establish effective spatial, temporal, and attribute query and reporting operations in disaster databases/systems.

1.4. Proposed prototype system

Many case studies and practical information systems in the last decade have demonstrated that a three-tier system configuration is very suitable for development in large data volume database implementation for efficient support of ad hoc analytical processing and information manipulation and analysis (Maguire et al., 2005). Hence, it is a three-tier architecture, consisting of presentation, business logic and data/resources, that is implemented in the proposed system. The presentation tier is the front-end interface with which users interact with the system. It runs as a client on the user's desktop PC. The presentation tier includes two parts: User Interface (UI) for end users to interact with the system and Application Programming Interface (API) for developers to interact with the underlying component blocks of the system. The business logic is used for validation and runs as process functions on a middle-tier

application server. The business logic tier consists of the web server and the application server. The web server will cope with the presentation tier and transfer user requests to the application server, and then the application server will implement the business logic and transfer the interpreted requests to the next tier – data tier. The data tier runs on a data server, and consists of a DBMS that stores all the datasets and the database server that manages the data access to the database. The database server will retrieve the information requested from the database and return the results.

The three-tier prototype system will be developed on a platform consisting of Oracle 10g, ArcSDE, ArcGIS Server, Apache and Tomcat (Johnston, 2004). Oracle 10g provides efficient, reliable, secure data management for high volume on-line transaction processing environments, query-intensive data warehouses, and demanding Internet applications (Greenwald et al., 2004, Abramson et al., 2004). With the spatial component, it is also capable for effective spatial data management. Therefore, Oracle 10g is selected as a DBMS in this study. ArcSDE can be phased in as a spatial data access server that allows for administering spatial data stored in a relational DBMS and provides access to data required for client applications such as ArcGIS Desktop functions, ArcGIS Server and custom applications (Environmental Systems Research Institute (Redlands Calif.), 2004). With capabilities for supporting concurrent multi-user editing and critical GIS data management workflows, Oracle will be installed and used as a data server in the proposed system. ArcGIS Server is designed for effective and efficient distribution of data and information and dissemination of GIS functionality (such as geo-database management and replication; publishing, mapping, editing, and geoprocessing) to internal and external end users via Internet services and applications (Environmental Systems Research Institute, 2004, Zeiler, 1999). Hence, ArcGIS Server is employed as the application server in the system. Apache, a well-known web server, and Tomcat, a widely used web servlet engine, will be configured to operate as the web server in this study.

1.5. Thesis structure

The research outcomes from this study are documented in six chapters in the thesis (Figure 1-1). This first chapter presents an introduction to the entire research project, including the background, challenges, objectives, and expected deliverables.

Chapter Two analyses the users' needs and justifies the targeted research questions. It involves identifying the user groups, analysing the needs of natural disasters information from different user groups, and finding out users preferences on data and information accessing, querying, and reporting. Chapter Two also conducts a review on existing natural disaster databases to identify the needs for enhanced natural disaster information sharing.

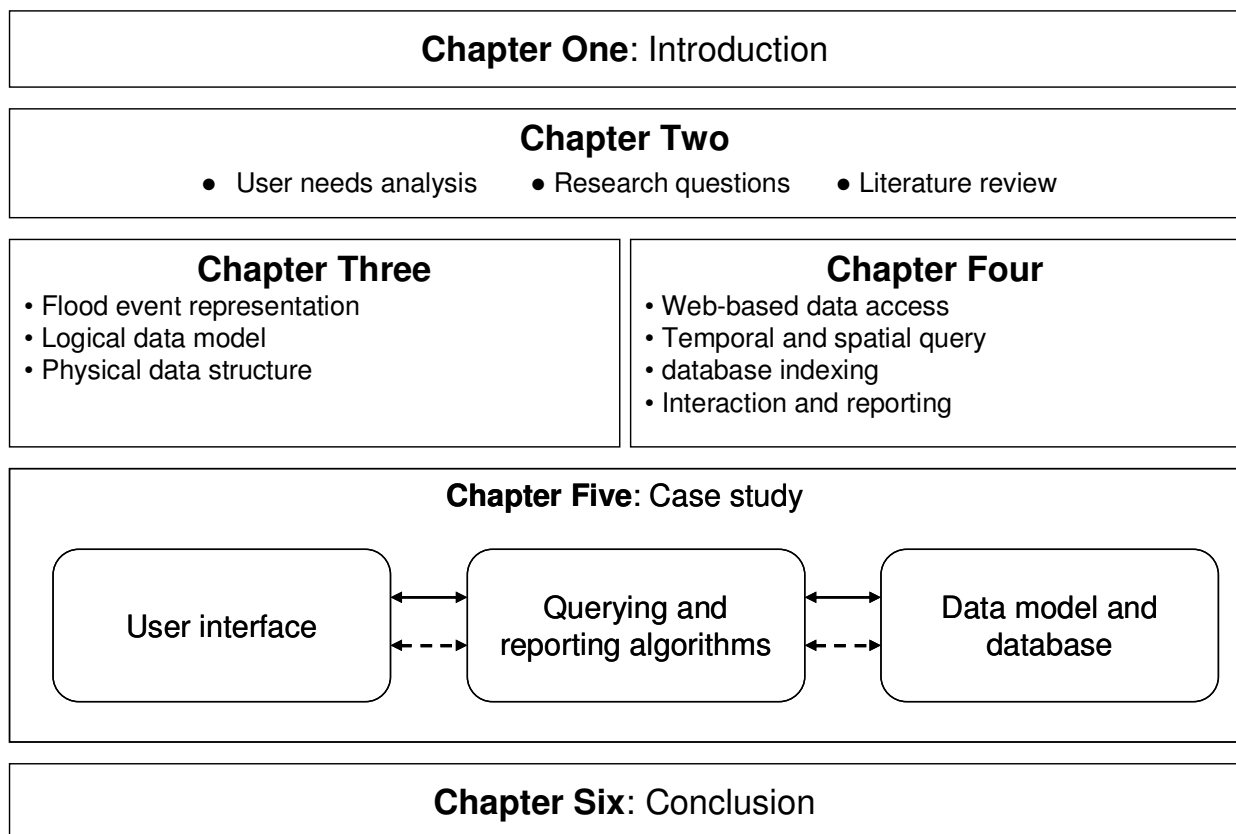


Figure 1-1 Chapter Structure

Chapter Three investigates the representation of natural disaster events, and as one of the most typical and damaging disaster types flooding was selected as the study case. Detailed investigations on flooding representation have been carried out from different aspects, including spatial representation of flooding extents, spatio-temporal representation of flooding events, and thematic representation of flooding impacts. Based on the findings of natural disaster information representation, different logical data models are examined, including geo-relational data model, event-based data model, and object-relational data model. This chapter also covers a

detailed discussion on the key elements of the physical data structure, including objects and classes, methods and interfaces, relationships and rules, as well as relations and keys.

Chapter Four presents the methods and technologies on information retrieval and reporting of natural disaster events. It explores the scheme of indexing and querying on both temporal and spatial dimensions, and investigates the methods for generating user specified summary statistics. Topics on interactive maps and data access via the Web are also discussed in this chapter.

Chapter Five describes the results of the case study, and discusses the outcome of the study in details based on the developed prototype system. This includes the area and datasets of the selected study case, the data model and data structure of the prototype system, the user interface and the underpinning algorithms for typical queries and reports. Sample outputs are showed at the end of this chapter as well.

Chapter Six, the final chapter, presents a summary of and some conclusions from, the study. Some recommendations are also made for further research.

2 INFORMATION NEEDS OF NATURAL DISASTER MITIGATION

2.1 Information needs of different user groups

2.1.1 User groups

Database systems, like disaster management systems, are developed to support many different users. These users are from different government departments, local councils, organizations and industrial companies. The local communities also need to access the information related to their vulnerabilities so that their important involvement in government decision-making process are not disregarded (Campagna, 2006).

Government agencies need access to comprehensive information on natural disasters to support their decision making throughout the cycle of disaster management (Zhang et al., 2003, Craglia and Wise, 2008). They play important roles in the data collection and maintenance. Information sharing amongst these government users is critical and complicated. The next section (2.1.2) will look into the details of the Australian government users' needs related to disaster management.

Non-government organizations also play a very important role in natural disaster management, especially in pre-disaster preparedness and post-disaster rehabilitation (Benson et al., 2001). Many NGOs specifically focus on providing humanitarian aid to disaster victims; hence information on past disasters is important for NGOs to optimize the use of resources.

Insurance companies need timely information on damage and loss after a disaster strikes, to evaluate the payout for recovery, and historical disaster information for a certain area, to estimate the risk of insuring a property in the area (Fattorelli and Frank, 2005, Jakeman and Letcher, 2003).

Researchers need comprehensive data on different aspects of natural disasters to support their studies on the disasters. These studies can be on various topics including disaster prediction, mitigation, emergency response and financial impact on natural disasters etc. However data collection for individual researchers or research institutes are usually expensive and time consuming (Decker, 2001, Greene, 2001). If a natural disaster database that combines all the data from different sources can be built and accessed by academic researchers across the globe, it would greatly facilitate the research on natural disasters. These new research outcomes can then be used to improve disaster management.

Communities worldwide have been facing an increase in variety and frequency of natural disasters, and the public in many parts of Australia are subject to the hazards of natural disasters, such as flood, bushfire, drought, cyclone and etc. Local communities are mostly concerned with the safety of their area and the natural disaster history of the region. Implementing Web-based GIS would provide local communities with easy access to environmental databases and allows them to participate in the environmental decision-making that could directly affect them (Culshaw et al., 2006, Masser et al., 1996).

2.1.2 Information needs for disaster emergency management

In Australia, the disaster emergency management cycle consists of four stages – prevention/mitigation, preparedness, response and recovery (Emergency Management Australia, 2004). At different stage of the disaster management process, different departments are involved and different information is needed to support the decision makings and guide the process activities.

- The prevention/mitigation activities aim to eliminate or reduce the impact of hazards and increase the resilience of the community subject to the disaster impact. Within this stage, the major activities include zoning/land-use management, building-use regulations and legislation to avoid developments at high risk area, and incentives/disincentives to encourage people move away from the low safety regions. In order to carry out these activities, the aggregated information based historical disaster events and the current physical environment, for example 20, 50, 100 year flood plain, and information of the

elements at risk, such as property, infrastructure, agriculture and etc, are essential and critical.

- The preparedness activities establish arrangements and plans and provide education and information to prepare the community to deal effectively with such emergencies and disasters as may eventuate. To set up emergency response plans and Evacuation plans, information on the evacuation area, such as population, transportation, and landform, and information of simulated or predicted disaster situation are very important. To provide public education, public information and training programs, the past experiences and historical disaster information are needed.
- The response activities include plan implementation, emergency declarations, warning messages, public information, registration and tracing, inform higher authorities, activate coordination centers, evacuation, mobilize resources, damage assessment, search and rescue, provide medical support, and provide immediate relief. Up-to-date information on disaster event in all aspects, including intensity, magnitude, affected area, trend and etc, are vital for decision making at this stage. Information on affected area, such as damages and losses, and information for resources are also crucial.
- The recovery activities are to assist a community affected by disaster in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical well-being. The major activities include restoration of essential services and public assets, counseling programs, temporary housing, financial assistance, economic impact studies, and reconstructions. In this stage, information of the damages and losses caused by the disaster events are essential.

Many government departments and agencies are involved in the disaster emergency management.

Table 2-1 shows all the agencies related to the flood emergency management and their responsibilities and involvements at four different stages. These agencies play different roles in the flood emergency management related activities and require different information. The information system needs to manage all the related information under clear and comprehensive guidelines, which for the data collection and management agencies for information sharing

purpose. In Australia, information related to water and flood are collected and managed at different agencies (see the detail in Table 2-2), and so facility to integrate with other information systems (i.e. transport information system and water resource information management system) must be arranged.

Table 2-1 Broad areas of responsibility, major public agencies, flood emergency management (Emergency Management Australia, 1999b)

Agency		Flood Emergency Management Component			
Jurisdiction	Nature	Prevention	Preparedness	Response	Recovery
Local	Local agency	✓✓✓	✓✓	✓✓	✓✓
State and Territory	Emergency Services	✓	✓✓✓	✓✓✓	✓
	Recovery agency		✓	✓	✓✓
	Technical agencies	✓✓	✓	✓	
Common-wealth	Bureau of Meteorology		✓	✓✓	
	Emergency Management Australia	✓	✓✓	✓✓	✓
	Dept of Transport & Regional Services	✓			✓
	Dept of Finance				✓✓
	Telstra				✓

Key: The number of ticks denotes degree of involvement of the listed agency with the listed activity, therefore, ✓✓✓ denotes major involvement, ✓✓ moderate involvement, and ✓ some involvement.

Table 2-2 Information sources and responsible agencies (Emergency Management Australia, 1999a)

Information Source available From	Available from
Flood studies	Councils, catchment management authorities, state emergency service, state/territory governments, libraries
Floodplain management studies	Councils, catchment management authorities, state emergency service, state/territory governments, libraries
Coastal zone management studies	Councils, state emergency service, state/territory governments, libraries
Dam-break studies	Dam owners
Levee studies	Councils, state water and floodplain management agencies, state emergency service, libraries
Historical records	Councils, catchment management authorities, state emergency service, media, historical societies, museums, community members
Flood mitigation design studies	Councils, operators of flood mitigation schemes
road and infrastructure design studies	road owners
Buildings, infrastructure and people, including census information	Councils, catchment management authorities, Australian government
Community experiences	Personal histories, newspaper archives

2.2 Importance of historical disaster data

2.2.1 Introduction

Historical disaster data is an integral part of the knowledge base on disasters, disaster impacts and disaster scenarios. With the support of information on baseline situations, records of historical disasters are essential to our understanding of current disaster risks, the effectiveness of past disaster mitigation efforts, and future scenarios or trends of disaster impact (Liu, 2005).

Records on the spatial, temporal and thematic aspects of historical disaster events are an essential part of current disaster study and risk analysis. Historical disaster data have been widely used as the base input data for the formulation of many risk assessment models around the world to determine the risk level and potential impact of disaster, and the quality and quantity of historical data have great influence on disaster prediction and preparedness (Amin and Goldstein, 2008). Moreover, information on past disasters can provide a valuable reference to disaster mitigation and emergency response. Thus, information on historical disasters is crucial for reducing disaster impacts in the future (Li et al., 2007a, Mansourian et al., 2006, Oosterom et al., 2005, Prestipino, 2004).

2.2.2 Risk assessment, mitigation and emergency response

Disasters like bushfires, earthquakes and floods have occurred in areas and seasons known to be more prone to these natural disasters. The damages, losses and costs of these disasters are directly related to the exposure and vulnerability of the affected communities and their living infrastructure. Analysis on geographical attributes of past events can provide spatial characteristics for different types of disasters in a specific region, whilst analysis on the time of these events can produce the temporal pattern for the type of disaster. Information on historical disaster impacts provides important references in disaster mitigation for avoiding or mitigating harm from natural disasters and for recovering from disasters. However, there exist few proper risk assessment studies and there are rarely adequate plans for disaster preparedness or risk mitigation. In many instances it has been said afterwards that if risk assessment studies had been adequately executed and emergency management plans had been in place, the death toll and level of destruction would have been minimized (Stanganelli, 2008).

The risk assessment of natural disasters is the key part in disaster preparedness and involves the assessment of both the probability of natural disaster occurrences and the degree of damage caused by natural disasters (Srinivas and Nakagawa, 2008). Historical data plays a very important role in both aspects. As mentioned earlier, historical disaster data is used as the base input data for the formulation of many risk assessment models, and will influence the modeled risk levels. Therefore, the quality and quantity of historical data has a great impact on the accuracy of the risk assessment models.

Effective risk mitigation can reduce the impacts of disasters. To be effective, the mitigation measures need to be developed with a good understanding of the characteristics and behaviors of hazards, the exposure and vulnerability of key elements at risk, including people, buildings and critical infrastructures, and the likelihood of interaction in space and time between the risky hazards and these elements at risk. Risk mitigation measures may include financial, planning and legislative measures for avoiding the possible interactions between hazards and the elements at risk wherever feasible, for enhancing the resilience of the elements at risk or changing the environment when and where the interaction are unavoidable (Mansourian et al., 2006).

Emergency management today focuses less on passive and often chaotic responses but more on proactive and effective risk mitigations. Where emergency responses can not be avoided, these responses are expected to be executed in a well-prepared manner based on good records and analysis of the spatial, temporal and thematic aspects of past events, reliable accounts of baseline situations, and timely monitoring of the currently unfolding event. Historical data is used widely in the emergency management of disasters to better evaluate the current situation and provide analytical support in the decision-making process. These past occurrences can help decision makers better understand the scenarios and risks involved, and take an appropriate course of action in a timely manner (Johnson et al., 1997, Maantay et al., 2006).

2.2.3 Conclusion

The importance of historical data management to effective emergency management, risk mitigation and disaster impact reduction cannot be underestimated. An inventory of historical disaster events - including records on what disasters occurred where and when, what were the damages, losses and costs, and what and who were impacted - will contribute significantly to the formulation of integrated and comprehensive emergency management plans.

To achieve cost-effective, evidence-based disaster impact reduction, this knowledge base should be constructed in a way that clearly establishes the correlations between the hazards, the vulnerable communities and the actual disaster impacts. Data on the location, extent, timing and impact of disaster events should be collected in a timely and consistent manner with well documented metadata. The data as well as other contextual information including reliable records on baseline situations should be made easily and widely accessible to all users, This

way, the questions about what, who, when and where in risk analysis, risk mitigation and emergency management can be answered more efficiently and effectively (Figure 2-1).

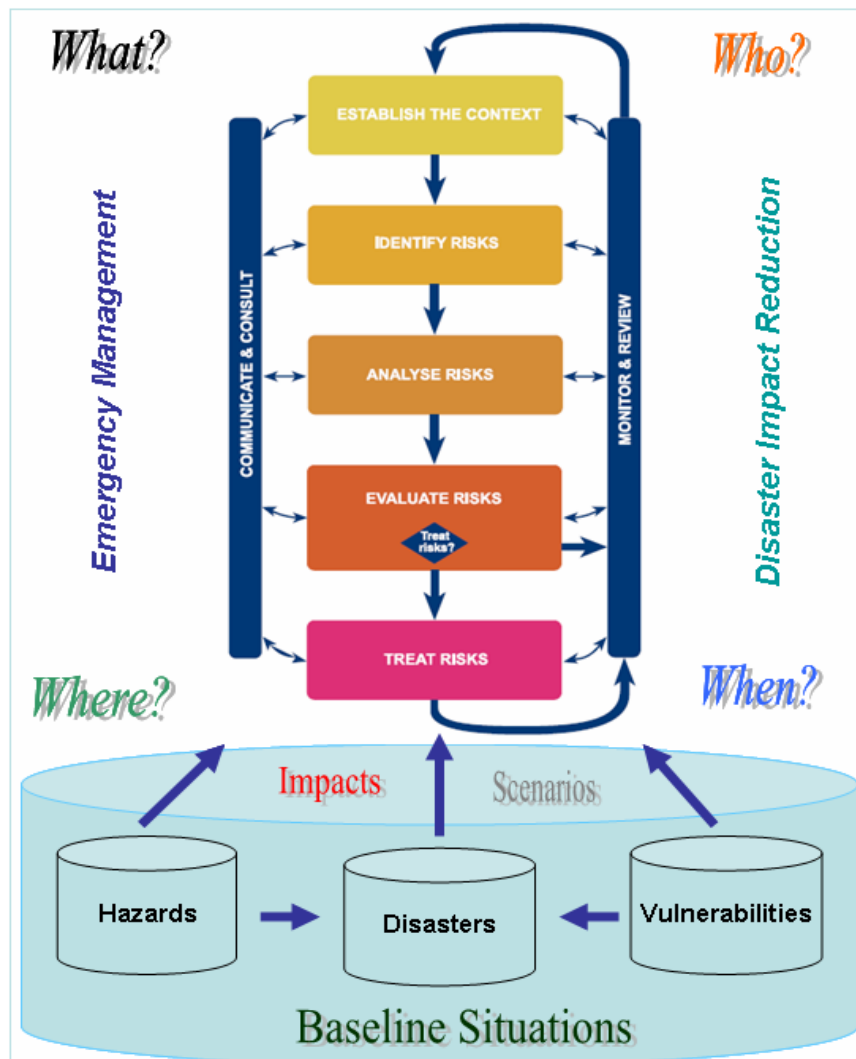


Figure 2-1 Guiding principles of disaster database enhancement (Liu, 2005)

2.3 Information elements of natural disasters

Natural disasters are dynamic and complex in nature, and will vary dramatically in a space-time context. To efficiently and effectively represent disasters and manage disaster information, the data on natural disasters should include at least the following four elements (Chang, 2004, Egenhofer and Mark, 2002).

The spatial element of a disaster event describes where and over which extent in the geographic space the disaster event unfolded (Goodchild, 1992b, Theobald, 2007). The extents of an occurred natural hazard and the locations of affected people, properties and infrastructures, is an integral part in disaster representation and is crucial to effective emergency management and disaster impact reduction. These datasets include properties, roads, infrastructures, points of interests (e.g. hospitals), administrative areas, elevation and so on. When a natural disaster strikes, up-to-date and accurate spatial information is essential to help save lives and mitigate the effects of the disaster. For effective disaster mitigation and reliable risk assessment, spatial information on historical disaster events should be used to analyse the geographical pattern of the impacts of natural disasters.

Temporal information represents when the disaster event begins and ends, how long it lasts, and how fast the event unfolds. Natural disasters take place in a certain place but their occurrence is not instantaneous (Alcantara-Ayala, 2002). For most disasters, as the time changes the geographical extent of impact from the disaster will also change. Therefore time is an integrated dimension in the representation of natural disasters. In addition, temporal information is the key to discovering the frequency and temporal pattern of natural disasters from a disaster management perspective (Peuquet, 2005, Yuan, 1996).

Reliable and accurate thematic attributes associated with each disaster event are fundamental to improve our understanding of the impacts of natural disasters. Good accounts on the magnitude, frequency and intensity, and speed of development of different types of hazards and accurate records on the elements damaged, the levels of damages, the amount of losses and costs, and to whom these damages, losses and costs occurred are fundamental for characterizing the likelihood of hazard occurrence and the vulnerability or resilience of elements at risk, conducting sensible risk assessment, and anticipating future scenarios.

Impacts of natural disasters include damages to humans, buildings, structures, infrastructure, crops, livestock, cultural heritages and the environment; as well as losses and costs to individuals, communities, businesses, and different levels of governments (Liu, 2005, Goodchild, 2006). Information on the impacts of past disasters is important in gaining a better understanding of the impacts of natural disasters, formulating useful emergency management and risk mitigation plans, and minimizing the damage and cost in the future.

2.4 Natural disaster information sharing

Information on natural disasters is important and valuable for all stakeholders involved in all phases of disaster and emergency management. It is important to integrate spatial-temporal dimensions of disasters into a disaster database to enable efficient and interactive querying and reporting of disaster information. It is also important to make such a database readily accessible to various users such as government agencies, non-government organizations, research institutes and local communities to support effective and efficient emergency responses, impact and risk assessments, and mitigation planning (Rinner et al., 2008, Rigaux et al., 2002b).

2.4.1 Information accessing

Timely and easy access to essential and usable information is crucial to the sharing of disaster information and in turn to the reduction of disaster impacts. But the establishment of effective mechanisms and efficient platforms of information access is a critical challenge (Plewe, 1997, Park and Kim, 2001, Zhong-Ren and Ming-Hsiang, 2003, Culshaw et al., 2006).

Access information on disasters and their impacts needs to be effective and efficient. The effectiveness of access to information on disasters and their impacts depends on how the disaster events and their impacts are represented conceptually and how these conceptual representations are organized logically and structure physically in a database. The efficiency of information access depends on both the design of the user interface through which information is searched and queried and the capacity and configuration of the communication networks that influence the speeds at which the transmission of requests for information and the required information between databases and users (see chapter 3 for more detailed discussions) can be facilitated.

Many cases proved that the Internet is a great platform for information publishing and accessing (Rinner et al., 2008, Zhong-Ren and Ming-Hsiang, 2003, Wang and Cheng, 2008). With the latest advances in Internet and communication technologies, combined with robust database systems, users from different locations around the world with various devices can rapidly access the information simultaneously. Moreover, with the highly developed web-GIS technologies such as ArcGIS Server and ArcIMS, spatial information can be published and delivered via the Internet as well (Johnston, 2004). It is desirable to have a system developed with these

technologies to enable efficient and rapid information accessing on natural disasters in both spatial and temporal dimensions for a variety of users from government agencies, non-government organizations, research institutes and local communities.

2.4.2 Information querying

Information querying is the key aspect for users who want to retrieve specific information on natural disasters. Therefore efficient and interactive queries for different user perspectives should be supported in a disaster database (Li et al., 2007b, Wang et al., 2009). To enable different user groups have flexible access to their required information or to retrieve different information on natural disasters in different dimensions, multi-mode database queries, including map-based and table-based spatial-, temporal-, and attribute-oriented queries should be supported.

To achieve effective information querying and ensure the quality of query results, certain database techniques such as indexing and caching should be implemented in the database management system. Furthermore, intelligent searching methods and a user-friendly interface should also be incorporated to facilitate the querying process.

2.4.3 Information reporting

Information reporting is another important aspect for information sharing among users who need to use the disaster information. Compared with the information querying, information reporting aims at provide more customizable summaries or presentations of queried information on natural disasters (Parent et al., 2006). Different forms of reports, such as statistical report with charts, aggregated tables of figures, and detailed reports with maps, should be supported by the reporting tools. These reports can be very useful for revealing the characteristics of the existing natural disasters, analyzing their current patterns, and predicting future scenarios. For example, a report with a trend chart of all the flooding events over the last 50 years in a specific area can be very helpful for evaluating the safety of that area from future floods, assuming the catchment hydrology has not changed much.

2.5 Limitations of existing systems

In the past decade, considerable research effort has been directed towards the establishment of databases on historic disasters. As already mentioned, many disaster databases have been built. However, most of these databases are primarily lists of disaster events with very limited support for map-based querying and reporting operations (Liu, 2005).

There have been a number of flood risk management initiatives designed to heighten awareness of socio-economic risks to floods, including the United Nations' International Decade for Natural Disaster Reduction (1990s) followed by the recent United Nations' World Disaster Reduction Campaigns (Levy et al., 2007). In addition to questioning the overall effectiveness of the hard (structural) approach to flood management ("keep floods away from people"), the panel warns that governments are being held increasingly liable for flood damages that result when natural flooding patterns are modified with flood control systems (often to encourage flood plain encroachment) or when such systems are not properly designed and maintained. In light of these social, legal and economic challenges, European governments have taken the lead in promoting soft (non-structural) flood risk management strategies by keeping people away from floods (Levy et al., 2007).

While many historical disaster databases/systems are currently available (Goodchild, 2006), very few of them are well-integrated within spatial modeling environments (GIS) and are capable of spatial and temporal information querying and reporting. In this research, three well-known web-based natural disaster databases have been investigated, including EM-DAT (The international disaster database) developed by the centre for research on the epidemiology of disasters (CRED), the Canadian Disaster database developed by Public Safety of Canada, and EMA Disaster Database developed by Emergency Management of Australia. All these systems are text based, which only support of attribute queries on historical disasters, but not map-based spatial queries or mapping functionalities.

To conclude, this chapter firstly explored the potential user groups and their needs on disaster information, and investigated the information needs from a disaster mitigation and management perspective. Then the importance and usage of historical disaster information has been discussed. Thirdly, the research examined the characteristics of natural disasters and identified the key

perspectives of information sharing on natural disasters. Lastly, the current disaster systems and their limitations have been discussed.

3. DATA MODEL AND DATA STRUCTURE

3.1. Representation of Natural Disasters

A natural disaster is defined as the consequence of a natural hazard on humans and their living environments, causing serious disruptions to the normal functioning of a community or a society (Quarantelli, 1998). The impact of a natural disaster is so devastating and it is beyond the day-to-day capacity of the local community to accommodate and the prescribed statutory local authorities to respond to, and it requires special mobilization and organization of resources other than those normally available to those local communities and authorities (Emergency Management Australia, 2004). Natural disasters have caused significant economic, social, financial, property and infrastructure damages as well as the tragic loss of human lives each year (Kondratyev et al., 2006).

A hazard is a “source of potential harm, or a situation with a potential to cause loss” (Emergency Management Australia, 2004). Natural hazards involve extraordinary natural earth surface processes which may interfere adversely with human activity, including severe meteorological events such as hails, cyclones, severe storms, violent geological events such as earthquakes and volcanic eruptions, and geomorphologic-hydrological events such as tsunamis, landslides and floods which can be regarded as secondary consequences of other natural hazards. For example, floods can be caused by severe storms and an earthquake may trigger landslides.

Natural disasters result from the interaction between the physical impact of natural hazards and the vulnerability of communities and their environments (Rigaux et al., 2002a). Natural hazards are complex events which vary greatly in their frequency, speed of onset, duration and areas affected. The degree of susceptibility and resilience of the community and environment to natural hazards also vary greatly in space and time. There are four fundamental dimensions in natural disasters – time, space, magnitude and intensity. As disasters unfold, time is used to record when each event starts and ends and how long each lasts, while space is used to describe where and to what extent the events occur. Magnitude indicates the size of a physical event or the degree of departure from some long-term mean values, and intensity refers to the size and

concentration of impacts or other effects. These four elements constitute the key aspects of natural disaster representation and modeling, as it describes and defines the main features of a disaster event.

In addition to these four dimensions of representing a natural disaster, the level of impact is another critical part of disaster representation and data modeling. This dimension describes the natural disasters from the human and environmental perspective. A natural event itself will not be defined as a disaster unless it generates tangible damage and impact on human beings. The impacts of natural hazards have been conventionally measured through changes in human, social and economic capital. These are typically represented by stock variables such as population, property and infrastructure, livestock, and agricultural land (Patwardhan and Sharma, 2005). The consequences of a disastrous event may be long term and/or may even irreversibly affect the economic and social structures and the environment of the affected regions.

In conclusion, the very complex processes that lead to extreme natural events and hence to natural hazards and disasters are difficult to understand without modelling. It is vital to model these disastrous events using appropriate data models and effective GIS technologies. The natural disaster management systems are considered as a synthesis of geospatial and temporal data as well as proper data models that supports disaster data analysis and decision making (Al-Sabhan et al., 2003).

3.2. Flood event representation

Floods are the most common natural disaster worldwide; almost one in five natural disasters is a flood (IFRCRCS, 1993). It is also one of the most frequent and damaging disasters in Australia with annual losses of over \$300 million in recent years (Wolski et al., 2006). Floods are usually classified on the basis of cause into two main categories: riverine and coastal floods. In Australia, coastal floods are not very common and are not considered a severe natural disaster, except some low-lying areas adjacent to coastal lagoons, tidal inlets and/or estuaries (Wheeler et al. 2008). The majority of floods in Australia are riverine and mostly caused by excessive rainfall.

In this research, riverine floods have been selected as a case study for analyzing the characteristics of natural disasters as events, and for investigating its representation of natural disasters from different aspects, including spatial representation, spatio-temporal representation and thematic attributes of disaster and disaster impact.

3.2.1. Spatial representation of flood events

A flood is an overflow or accumulation of an expanse of water that submerges land. Flood representation depends on hydrographic, hydrologic and hydraulic descriptions of surface water movements, and involves elements such as surface elevation, actual rivers, streams, water bodies and relationships among them.

Flood representation in a GIS may include the following basic thematic layers:

- 1) A raster elevation grid, also known as a digital elevation model (DEM), or a vector-based triangulated irregular network (TIN) surface model, for deriving the streams or a drainage network, drainage area and providing cartographic background.
- 2) A digital orthophotography, for providing a background for graphical displays which can also be used to fix DEM errors.
- 3) A hydrography layer, typically including natural and man made water features, such as the network of rivers and streams, and lakes, which can be used for visualisation and stream analysis. .
- 4) Rainfall response areas which are critical for flood or drought estimations, complement topographic maps and orthophotos, and illustrate broad patterns of soils, and vegetation and land use in terms of their contribution to rainfall.
- 5) Drainage areas, also called catchments, watersheds or basins, and each covers a stream section, used to estimate the amount of water flows into rivers, based on water flow direction.
- 6) Hydro-graphic points, including the gauge stations on a stream network and structures such as dams, monitoring stations, pumping stations.
- 7) Detailed three-dimensional channel cross-section profiles, and longitudinal profiles along a river channel, which are used for hydraulic analysis and are important for flood extent mapping.

Other thematic spatial layers critical for flood representation include:

- 1) The flood extent, or the maximum extent of inundation resulting from each flood event
- 2) The flood depth, or the maximum inundation depth for each location within a flood extent
- 3) Contextual themes, such as population, properties, infrastructures, and roads, describing both the relative surroundings and the elements at risk of the flood event. As mentioned in previous chapters, disasters are the outcome of natural hazard interactions between human and society; therefore these contextual layers are important for representation and estimation of flood damages and impacts.

3.2.2. Spatio-temporal representation of flood events

All geospatial phenomena, including flood events, vary in space and evolve in time. The extent and duration of flood events vary greatly, and bring much complicity to spatio-temporal patterns of flood impact.

Flood hydrograph is one of the methods that visually represent a flooding event over time. It shows the discharge, depth, velocity or other properties of water flow with respect to time for a given point on a stream. The diagram below depicts the whole process of a flood event observed at a given location (Figure 3-1). In the graph, a decrease of stream flow in a dry season is shown as AX; rainfalls begin at time X and the discharge rapidly increases to its peak flow at time Y; the discharge peak occurs (Y) soon after the rainfall stops. It is clear that flooding is a dynamic process that expands with time, and the time is an important element in the representation of flooding events.

The flood hydrograph is useful only for estimating the start, duration and end time of a flood event for one static location. From catchment-wide perspective, a spatial aspect must be involved and integrated with time to represent the dynamic processes and impacts of flood events (Goodchild, 2006). Therefore, a spatio-temporal framework is called to represent the changes in spatial extents and the thematic features of the dynamic flood process over time.

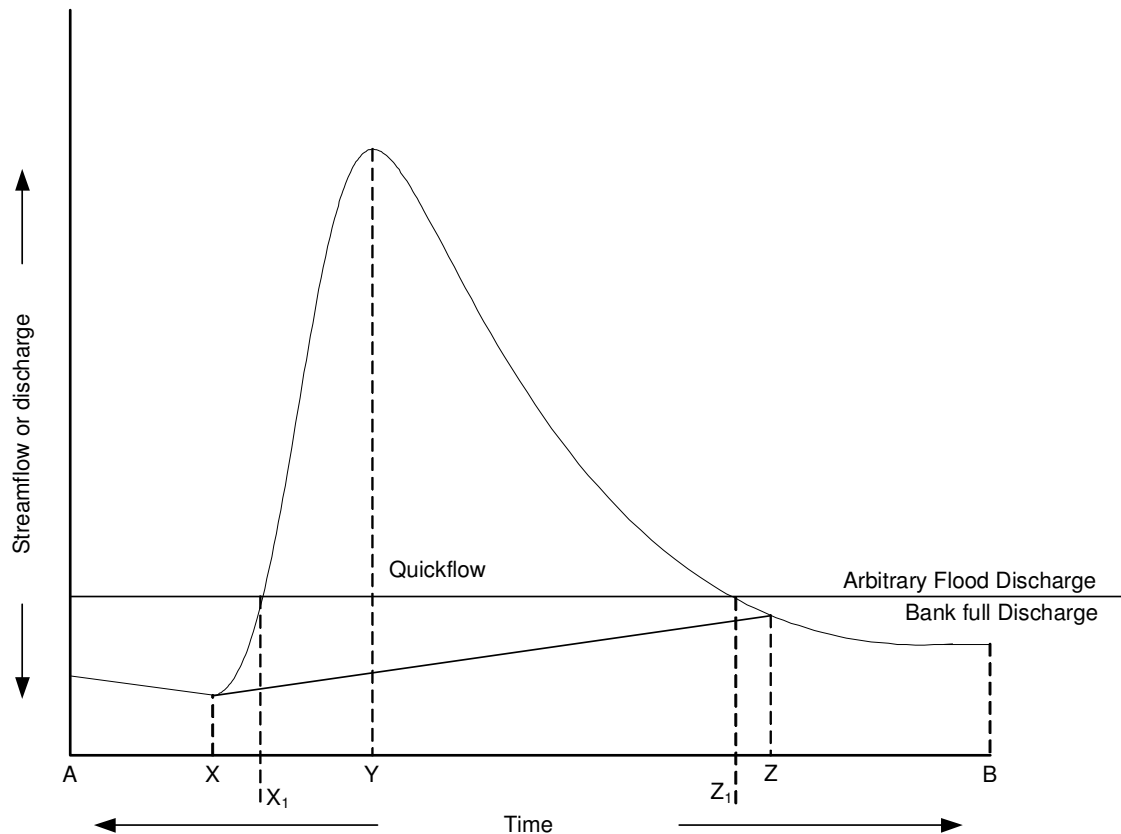


Figure 3-1 Hydrograph of a typical flooding event observed at a given location

Source: Modified from (Hoyt and Langbein, 1955)

3.2.3. Thematic attributes of flooding events

Thematic attributes of a flood event describe the distinctive characteristics of the flood event such as its duration, magnitude and intensity.

Duration indicates the time period for the flooding event from the start to the end. Duration may vary greatly for different floods in different areas. For example, the duration of flash floods is often measured in minutes while seasonal floods can last for months. In general, a longer duration of a flooding event causes greater impacts.

The magnitude indicates the size of a flood event compared with some long-term mean values that define the strength of a flood event. Floods are usually categorized by their magnitude, for

example a twenty-year flood, a fifty-year flood or a hundred-year flood (Emergency Management Australia, 1999a).

Intensity refers to the size and concentration of impacts. River floods are usually intensified by catchment characteristics, drainage network and channel factors. Most of them influence the speed of water movement in the catchment. The duration, magnitude and intensity of a flood event are fundamental to flood representation. In most cases, these key thematic attributes have significant bearings on the disaster damages and impacts.

3.2.4. Flooding impact

Natural disasters, including flooding, are extreme geophysical events causing unexpected damage to human lives and properties. If an extreme physical event, for example a severe flood, happened in a remote or unpopulated region and had no impact on human community, it will not be considered a natural disaster, even though it may have changed the entire floodplain drastically (Patwardhan and Sharma, 2005). Thus, the impact, which is the negative economic and social consequences caused by extreme natural events that affect human activities, is a critical and essential part in disaster representation.

The damage resulting from floods can be classified into two main categories: direct damage and indirect damage. The damage that occurs immediately after a flood, as a result of the direct physical contact of flood water with people or damageable properties, is called direct damage (Greene, 2000). For example, floodwater damage to cars or housing properties. On the contrary, indirect damage is the damage which occurs without direct contact with flood water but is the consequence of direct flood damage. Indirect damage often occurs over an extended period of time and is more difficult to estimate. For example, a business may not be damaged by direct contact with the flood but its sales could be decreased due to the reduced number of customers as a result of transport disruptions caused by the flood. In general, the geographical extent of indirect damage is usually broader than the areas of direct damage and it is more dependent on social, economical and geographical interactions between flood-affected zones.

Damage can be also categorized into tangible and intangible damages depending whether the damage is measurable in monetary terms or not. Tangible damages usually can be measured in monetary terms, such as the damage to a flooded property can be measured in dollars. The

damage unable to be assessed in the monetary term is called intangible damage. This damage is difficult to estimate as there are no systematic or agreed methods available to measure them. Loss of lives, injuries, stress, loss of heritage items and memorabilia are examples of intangible damage. They can be the most important consequences of flooding because they are items of a sentimental value and often unable to be replaced or recovered by money or other means.

In conclusion, representation of flood disasters should incorporate geospatial, temporal as well as thematic data elements on flood events and their impact to support disaster analysis, modelling, and decision making. The logical data model for the flood disaster representation should combine both geographical information and hydrological information to enable a better flood modelling within GIS.

3.3. Logical data model

3.3.1. Data models in GIS

A data model is a simplification and logical organization of a) the complex real-world entities or events as distinctive objects, and b) the constraints on and relationships among these objects (Kovacs and van Bommel, 1998). A data model describes how the entities or events are represented and accessed, the data structure and their characteristics, constraints, transformations and the interrelationship among the data elements. A well-developed data model can facilitate an efficient data storage, management and usage, as well as foster improved understanding of the selected real-world entity or event (Kovacs and van Bommel, 1998).

In the past fifty years of GIS development, there have been many important discussions on GIS data models and geographic representations. The earliest GIS data models are founded on Berry's geographic matrix (Berry, 1964) and Sinton's three-dimensional schema (Sinton, 1978). In the 1970s, topological data structures were developed to define geospatial relationships among spatial objects based on their locations in space, and in the 1980s, relational data models were introduced and widely used to implement topological data structures in GIS (Worboys and Duckham, 2004). In the 1990s, an object-oriented concept was broadly accepted and received, where the geospatial world was modeled in the context of objects (Egenhofer et al., 1999,

Worboys et al., 1990). Later, the object-relational data model was proposed to utilize the object-oriented theory in more conventional relational database technology. In recent times, aspects of time (Peuquet, 2002, Langran, 1992) and three dimensional spatial representations have also been incorporated into GIS data models. Time brought a significant proliferation of complexity into GIS data models, and many discussions and studies have been carried out on this topic. Essential findings include the event-based spatio-temporal data model (Peuquet and Duan, 1995), the concept of discrete objects and continuous fields, and the theory of geo-atom (Goodchild et al., 2007). However more investigations are still undergoing to imply time as a new dimension in real world applications.

Currently the most popular data models in digital geospatial data management systems are relational models, object-oriented data models and object-relational data models, which apply object-oriented technology in the spatial database management system. The following sections will discuss the data models for disaster representation in detail, including a discussion on spatio-temporal data models.

3.3.2. Relational data Model

As one of the most widely used data models, relational data model manages data with collections of tables, which is also called relations. Individual records are stored as rows in the tables, and attribute data are stored in columns. Tables are logically associated to each other by communal attributes, and are usually normalized to minimize redundancy.

Spatial data is more complex compared to traditional business data since it contains the geometry or shape of the object, its spatial location and extent on the earth's surface along with other spatial properties. In relational data models, mathematical construct is used for representing geographic objects or surfaces. Typical geospatial representation methods include the vector data model, the raster data model and the triangulated irregular network data model (Peuquet, 1984). The vector data model represents geography as collections of points, lines, polygons and their derivatives; the raster data model represents geography as cell matrixes that store numeric values; and the triangulated irregular network (TIN) data model represents geography as sets of contiguous, non-overlapping triangles (Arctur and zeiler, 2004).

However, the relational data model is limited with respect to semantic content and there are many issues with the design that are not naturally expressible in terms of relations (Worboys et al., 1990).

3.3.3. Object-oriented data model

Different from relational data model, object-oriented data model represents real world entities as a number of objects (e.g. flood events, properties and land), and class (object type) is used to define the abstraction of a collection of objects with properties in common (Worboys et al., 1990), which are much more advanced in encapsulation and extensibility. Each object has its own properties and behaviors. The properties of an object are represented as attributes, which describe the state of the object. The behaviors of an object are represented as methods, which classify the actions or operations it can perform. Objects can act on, or can be acted upon by other objects. The state of objects can be changed by the actions and this change of state is referred to as an event (Bian, 2007). The relationship describes how objects are associated with each other. Basic relationships include inheritance, association, aggregation and composition (Borges et al., 2001).

Compared with relational model, the object-oriented data model allows for richer and more complex descriptions of the real world, better support for semantic content and sustainable multiple level of generalization, aggregation and association (Tomilinson, 2003). However, due to the complexity of the natural phenomenon and the finite nature of computer environment, Bian (2007) pointed out that the continuous field natural of fluid mass such as water determines that the object-oriented data model is not suitable for such representation.

3.3.4. Object-relation data model

Object-relational model is one of the most recent expansions in logical data models. It employs object-oriented concepts and capabilities on top of a conventional relational database management system (RDBMS) (Tomilinson, 2003). The object-relational data model incorporates favourable characteristics of both the relational data model and object-oriented data model. . The object-relational data model extends the relational data model by adding abstract data type, which deploys the concept of class in the object-oriented data model, and the abstract data type enables a richer data structure without encapsulating the underlying data. Specialised

behaviours are also added in the relational data model, allowing better flexibility in representing real world objects and improving data integrity.

Compared to the object-oriented data model, the main advantages of the object-relational data model is its speed (fast execution), its ability to support SQL (Structured Query Language) and its ability to access RDBMS. As most commercial DBMS are RDBMS, the object-relational data model is one of most feasible forms of complex applications in GIS (Tomilinson, 2003).

3.3.5. Spatio-temporal data model

As discussed in previous sections, any natural phenomenon varies in space and time. The synthesis of spatial and time series of data has been a challenge for GIS systems because traditional geographic models do not support time. The management of spatio-temporal data has been intensively investigated for many years because the topic is becoming more and more important to many GIS applications, including emergency management.

The earliest method to capture the evolution between time and space used snapshots to represent the succession of the states of the reality. For example, temporal changes of a flooding event are represented in a collection of maps over the same hydrological catchment at different times. The images of flooding areas are captured based on a specific time interval to portray the changes over time. This type of representation simply employs the grid data model, and uses a sequence of spatially-registered grids to represent a thematic map layer (Peuquet and Duan, 1995). This snapshot approach is based on location, and the time is used as an additional property of the raster data image. Conceptually it is very straightforward. However its actual changes between two time points are hard to be retrieved or visualised, and can only be derived by comparing the pixel value differences between snapshots (Peuquet and Duan, 1995).

Event-based spatio-temporal data mode (ESTDM) is proposed in 1995 by Peuquet and Duan (Peuquet and Duan, 1995) to represent spatial changes over time. ESTDM is based on time as its organisational basis to facilitate analysis of temporal relationships and patterns of change through time, which is a time-based approach that temporally orders changes to locations within a pre-specified geographical area. In ESTDM, specific changes associated with time are stored, and the stored temporal location is called a time-stamp. It is assumed that each event list and its associated changes are related to a single thematic domain. In comparison to raster image data

handling, the vector data model offers a more effective information storage and retrieval and so is used in ESTDM. Time becomes a primary aspect in this model; representation of change is organised as a function of time. ESTDM is capable of three fundamental temporal-based retrieval tasks: (1) to retrieve location(s) at which changes occur at a given time, (2) to retrieve location(s) at which changes happen in a given temporal interval, and (3) to calculate the total area that has changed over a given temporal interval (Peuquet and Duan, 1995). The most significant contribution of ESTDM is that temporal manipulation on data and temporal-based spatial comparisons are established in the GIS context. Moreover, this data model is easily implemented with RDBMS, thus it has been adopted broadly in spatio-temporal database applications. However, the underlying temporal representation is discrete, and changes between two time stamps are lost and difficult to be recovered (Yuan, 2001).

Object-Event model is another approach invented to represent the spatial changes over time. Object-Event models such as GEM (Geospatial Event Model) extend the traditional object-based geospatial models and allow for dynamic analysis of spatial data (Rigaux et al., 2002a). Geospatial event models represent the entities of real world as objects or events. Entities compose reality according to their temporal mode of existence, and entities are represented as classes of geo-objects and geo-events, each of these may have thematic, spatial and temporal attributes, and relations to other geo-objects or geo-events. Also, events have spatio-temporal settings such as a point, a line or a polygon, and they may be instantaneous or they may extend on a finite interval of time. Object-Event models provide a foundation for modelling dynamic geospatial domains and the utility of the models have been already proven in some studies such as dynamic video scenes. However, the implementation of these models to represent the complex phenomena such as natural disasters is rather difficult due to the heterogeneity conflicts of evolving geospatial objects, events ontology and data acquisition limitations (Bian, 2007). Most models dealing with natural disasters or other environmental issues are based on the continuous theories. These models describe the changes through continuous time and space. However the computing environment is finite and discrete, it cannot provide infinite and continuous unit to store the continuous changes. On the other hand, it is impossible to measure infinite locations in space, because the data collection via current technologies (e.g. remote sensing) is not continuous measurement.

In recent years, discussion on spatio-temporal GIS is focused on spatio-temporal ontology, the discrete-object and continuous-field conceptualisations (Goodchild, 1992a) and object fields (Cova and Goodchild, 2002). Some new concepts such as the geo-dipole, spatio-temporal data modelling is moving towards a four dimensional representation which includes time, and may eventually motivate a new approach that is neither relational nor object-oriented (Goodchild et al., 2007).

3.3.6. Conclusions

Data models for different systems are arbitrarily different depending on the business rationales. Based on the proceeding discussions, the key requirements of a data model for representing the complex natural disaster events must be able effective in representing disastrous events in both spatial and temporal dimensions, and to facilitate management of thematic attribute data and information on damages and losses caused by these events (Jogn G., 2003). Due to the complexity of a disaster, an enormous volume of data may be involved, and data access capabilities and functionalities for querying and reporting discussed in chapter two are needed. The object-relational data model is selected for the representation of natural disaster events, e.g. flood in this study, considering its recognised advantages and suitability.

The logical data model is conceptually structured into three thematic levels (Figure 3-2), including the hydrological layer, the contextual layer and the flood event layer. The basic relationship among these three thematic layers is topological, such that spatial connection among spatial objects based on their location is maintained, and spatial definitions of entities can be stored in a non-redundant way (Peuquet, 1984). It should be always noted the contextual layers represent the real-world phenomena that constitute the response to hydrological events, the nature of which define the range of impacts and can be deduced from the attributes in the hydrological layers.

As shown in Figure 3-2, the spatio-temporal representation is applied only on the core thematic level, which is at the flood representation layer. This is to simplify the complexity of the representation of the highly dynamic process of flood events. Flood extents and overland extents with a time-stamp are organised based on an event-based data model to demonstrate the process of a flood event and to illustrate the spatial changes over a given temporal interval.

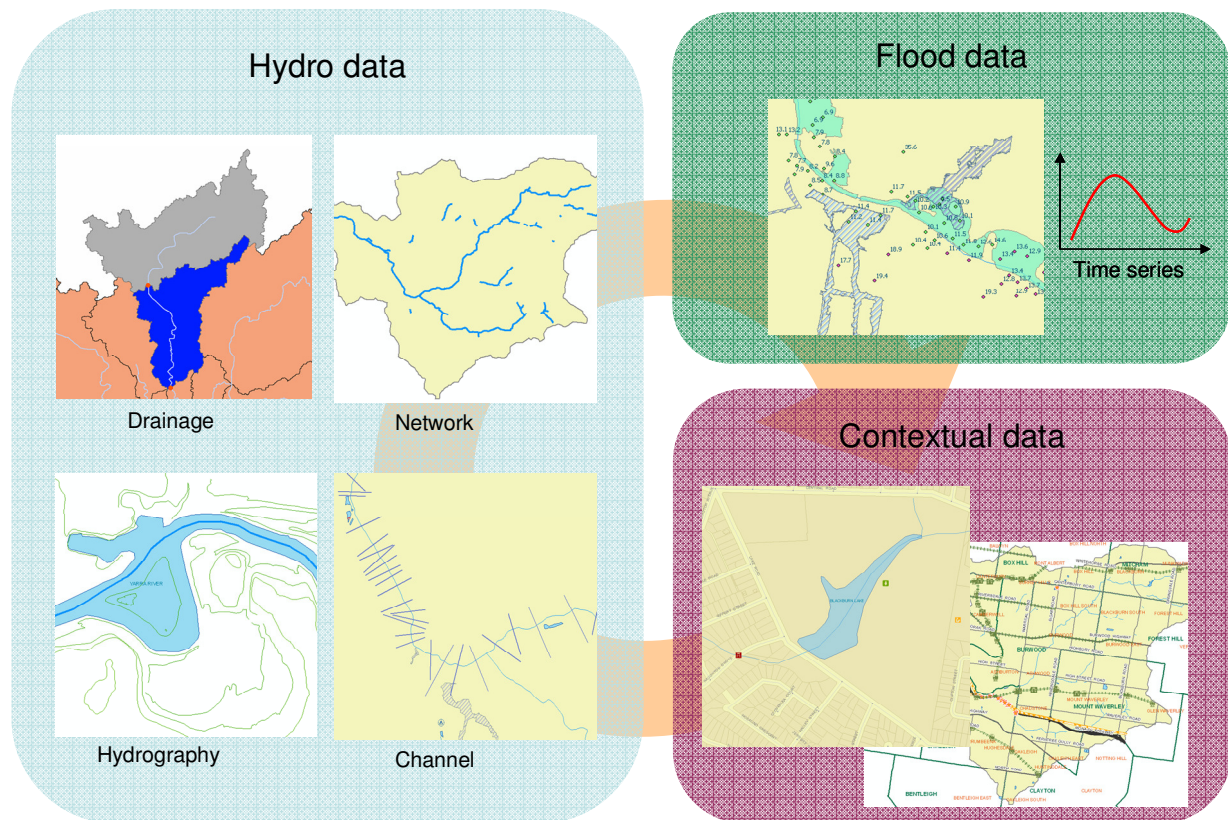


Figure 3-2 Conceptual data model

Based on the conceptual data model (Figure 3-2), a logical data model (Figure 3-3) is built to represent the data objects and to define the relationship among them. The hydrological representation consists of four subcategories: drainage, hydrography, network elements and channel details. ArcHydro data model, which is one of the best hydro data models with interoperability (Goodall and Maidment, 2009), is adopted and customised in this study. Flood feature layers represent the spatial extent and characteristics of the flood event, which includes the maximum flood boundaries, the overland extent, and the flood extent at different times. The tabular data of thematic flood-mapping properties supports generation of these representations.

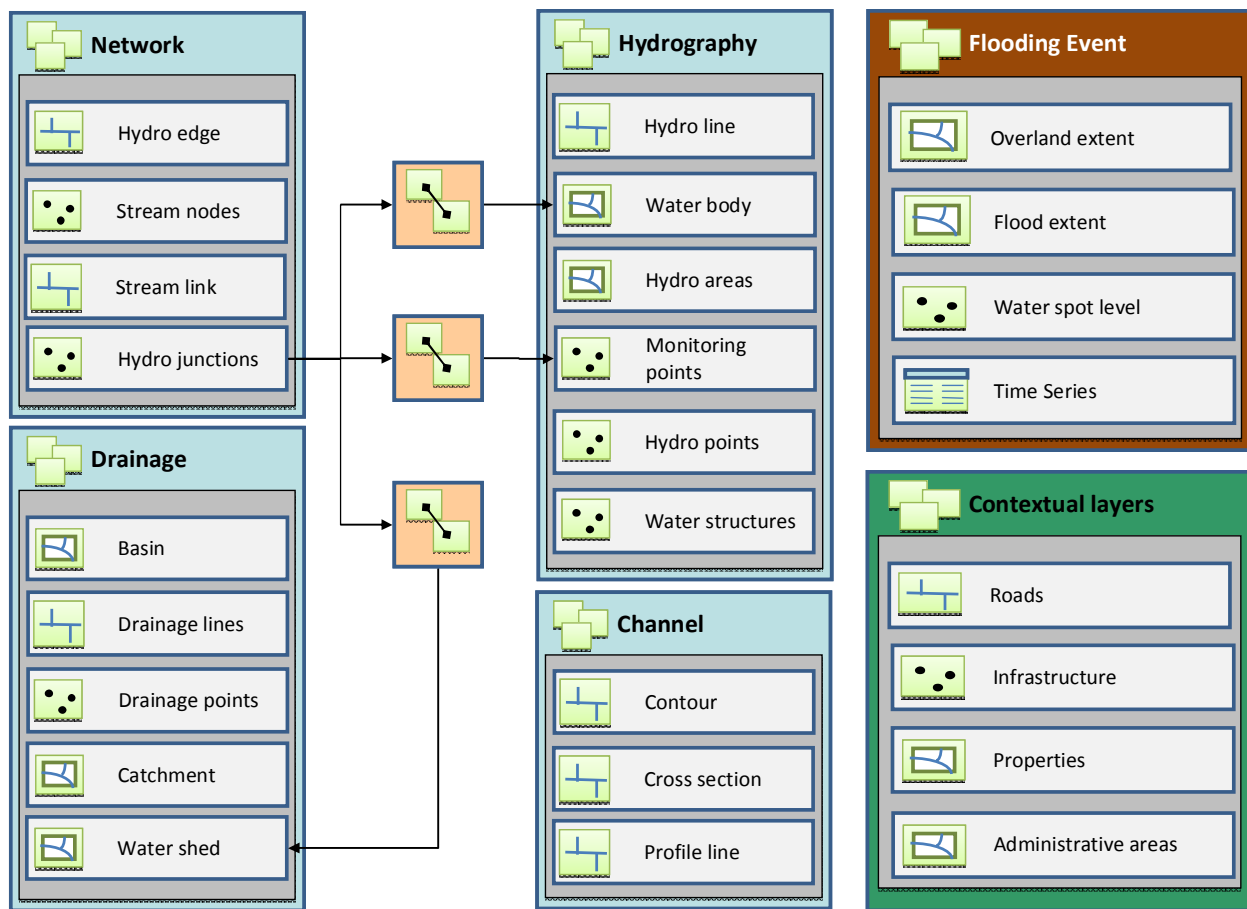


Figure 3-3 Logical data model

3.4. Physical data structure

Once the logical data model is validated and approved, a physical data structure can be built upon the data model so as to inform the database design. The physical data structure is a structured model that defines the content and constraints of each of the data objects corresponding to the data model, and describes the relationships among them. In this section, such data structure will be explored in detail.

3.4.1. Data structure of hydrological layers

The data objects involved in the hydrological representation are organized in the following four categories: Hydrograph, Drainage, Channel and Network. They are discussed in detail below and they feature in Table 3-1.

- Hydrography represents surface water features in the landscape, which include point layers such as hydro points, bridges, dam and water structures; line layers, for example hydro lines of rivers and streams; and polygon layers such as hydro areas and water bodies. These hydrographical features provide a visual and spatial reference and are important for understanding the context of a flooding event.
- Drainage features are derived from digital elevation models (DEM) to describe the manner of water flow on the landscape. Drainage features include basins, watersheds and catchments based on different levels of delineation. Basins are a set of administrative drainage areas for water resource management, which can be subdivided into watersheds or catchments; Watersheds and catchments are both a tessellation and subdivision of a basin into drainage areas. However watersheds are selected for specific hydrologic purposes while catchment areas are defined by a consistent set of physical rules. DEM is included in the drainage features as well, which describes the land surface terrain and can be used to define the drainage boundaries.
- Channels represent the three-dimensional model of stream channel bottoms, banks, and floodplains, which together determine the flow characteristics of the channel. Channel features include cross section lines that define the shape of the channel transverse to the stream flow, profile lines that identify the boundaries of a stream channel, and linear measures to hold distance values of cross sections and profile lines for measurement purposes.
- Network features are formed with connected sets of hydro junctions and hydro edges to show the pathways of water flow. Hydro junctions are used to represent the important point locations in the hydro network, such as the outlet of a water body. Hydro edges are the linear representations of streams, rivers and water bodies in a river system. The topological connection of hydro edges and junctions facilitates the understanding of water movement upstream and downstream within the network, which is important for the analysis of flood movements in this study.

Table 3-1 Descriptions of the key hydrological features

Name of Feature	Description
Hydrography	
Hydro Line	Line representations of river and stream lines, i.e. river central lines
Water Body	Polygon representations of water bodies
Hydro Area	Polygon representations of water features other than water bodies, i.e. wetland.
Monitoring Point	Locations of water monitoring sports
Hydro Point	Points representing hydro structures, i.e. bridge and dam
Water Structure	Points hydro structures other than hydro points, i.e. waterfall
Drainage	
Basin	Administrative drainage areas.
Drainage Line	Lines through the center of DEM-derived drainage path
Drainage Point	Points at the center of a DEM cells in DEM-derived drainage area
Catchment	Elementary drainage areas defined by physical rules
Water Shed	Sub areas of catchment for analysis
Channel	
Contour	Elevation contour lines
Cross Section	The transverses of channels
Profile Line	Longitudinal profiles of channels
Network	
Hydro Junction	Points of flow segments
Hydro Edge	Network of flow segments
Stream Link	Lines of line segments
Steam Nodes	Points of line segments

3.4.2. Data structure of contextual layers

The contextual layers are an essential representation background of a flood event and are crucial for the evaluation and estimation of the impact of a flood event and useful for the representation of the flooding reality. Floods directly interact and affect these contextual layers and cause damage and impact to these contextual objects. Contextual layers consist of administrative areas, properties, infrastructure, roads etc.

- Administrative areas, including suburbs, LGA (Local Government Area) and postcode areas etc are normally represented as polygons.
- Properties are the buildings and parcels, which can be represented as both points and polygons.
- Infrastructures including power lines, power stations railways etc are represented in different formats including points, lines and polygons.
- Roads represent the transportation network.
- Aerial photography is the imagery of the real world as photomaps (in aorthomosaic form), they offer contextual background.

3.4.3. Data structure of flood layers

Flood event representation is a core component of the data model. To support the representation of flood events in both spatial and temporal dimensions, flood data is stored with time stamp and organised with event-based modelling in mind. The implementation of the data model will be addressed in detail in the case study in chapter five.

3.5. Summary

According to Peuquet (1984), the major process of database design and definition facilitate model evolution from the vague to the specific. It is pointed out that the four hierarchical levels

of data abstraction can be utilized as reality, data model, data structure and file structure (Figure 3-4).

- Data model is an abstraction of the real world phenomenon and processes, which generates a conceptualization of reality with only the relevant properties in the domain of interest.
- Data structure is a representation of data arrangement, which is often expressed in structured models to define how data is stored and organized in databases.
- File structure is the data representation in storage hardware, which is normally managed by DBMS automatically.

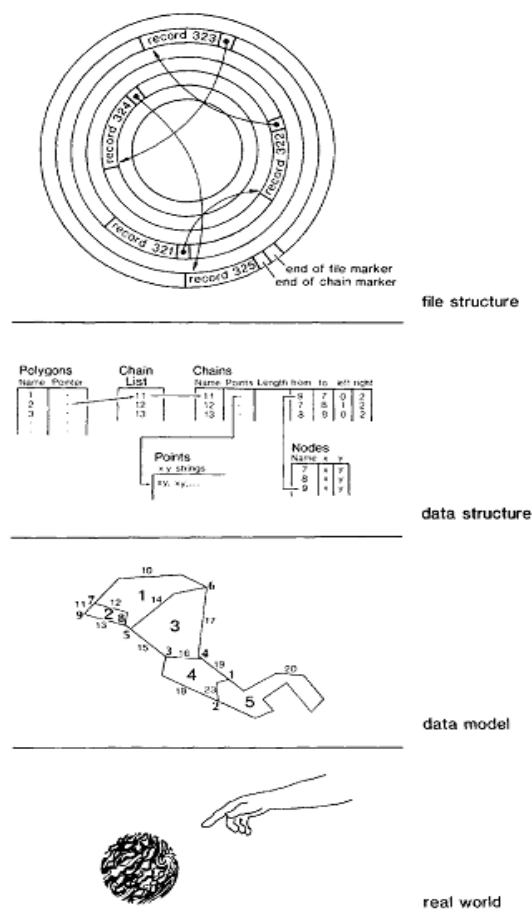


Figure 3-4 Hierarchy of data abstraction (Peuquet, 1984)

This chapter follows the hierarchy of the data abstraction (Figure 3-4). The reality issue has been discussed in Sections 3.1 and 3.2 as a representation of natural disasters and flooding events. Based on the characteristics of floods, the data model of flooding events has been developed in Section 3.3 based on a discussion and comparison of different data model types. Section 3.4

explored the data structure based on the data model, and defined the object classes and relationships.

4. INFORMATION ACCESS, RETRIEVAL AND REPORTING

The potential value of data and information, such as data on historical flood events and associated contextual geographical information, can only be realized when it is used in the knowledge generation and decision making processes. Datasets that are well organized with suitable logical data model is an essential prerequisite but not necessarily an adequate guarantee for effective and efficient information sharing. Easy access, fast retrieval and sound reporting of the information in GIS systems are demanded by users (Goodchild, 2007). This chapter will first review the web-based data access technologies, then exam the spatial and temporal querying and indexing methods and strategies, and finally look at the interactive user interfaces and approaches to reporting generation .

4.1. Web-based data access

Information sharing is desirable both for reducing the cost of data collection, which is expensive and time consuming, and for enabling broader applications of the collected datasets by more users. The potential value of the collected datasets can therefore be realized to a greater extent through information sharing.

Driven by the increasing needs for distributed data access and information sharing (Bugs et al., 2009, Culshaw et al., 2006, Davis, 2007), and by the rapid development of ITC technologies, more and more web-based data access platforms have been implemented throughout the world (Suzana, 2004, Zhong-Ren and Ming-Hsiang, 2003).

The following section is to discuss a) the advantages of the web-based system, system architecture, and b) two key issues related to the web-based GIS system. At the end of this section, the latest web 2.0 technologies will be discussed for next generation GIS applications (Bugs et al., 2009, Goodchild, 2007).

4.1.1. Advantages of web-based system

In the information era, reliable infrastructure for information management and sharing are critical for both public and private organizations (Park and Kim, 2001, Plewe, 1997). Compared with desktop based systems, web-based systems provide cost-effective and reliable technological solutions for information management and sharing. Properly developed web-based platforms allow global and flexible access around the clock for all connected datasets and users, via wired or wireless links, no matter where these datasets and users are located. Users, for example, are able to use their mobile devices to access the data physically located at different departments (Rinner et al., 2008). Allowing users for flexible access to a large amount of data resources enables the processes and outcome of both decision-making and knowledge generation.

In practice, a web-based system provides robust infrastructure for information sharing and database maintenance. Web-based systems, for example, allow simultaneous and remote access of historical disaster data collected and maintained by an emergency response department, the property data hosted and maintained by local city councils and framework geographic datasets hosted in different state and federal government agencies. All can be accessed by different users before, during or after an emergency of Web-GIS is implemented.

With web-based systems, database and information systems can be updated in the server side without disturbing the end users. This saves much time and work in system distributions and update. A signal update of software for desktop based systems is fraught with danger for large organizations, but not for the Web-based system. Furthermore, Web technologies are standards across different computer platforms, including UNIX or Windows systems, desktop computers or hand held devices, on Intranet or Internet. Consequently, the system development complications are reduced significantly. With web-based systems, better information sharing and efficient information management can be achieved, which is very important in large and multiple levels organizations.

From the users' point of view, a web-based system is easy to use with flexible access in terms of location, time and content, as far as the users have the communication connection, which is not a problem nowadays. Web-based systems support public participation, an important direction of GIS applications (Sieber, 2006, Bugs et al., 2009), in the decision-making processes. Through

public participation, web-based systems facilitate the effective and efficient mobilization and integration of resources and insights from different government agencies, from the full range of experts, local stakeholders and the general public as needed to generate suitable solutions and improved outcomes when facing different challenges imposed before, during or post particular events such as disasters.

4.1.2. Two key issues related to web-based GIS

Development of Web-based GIS is not a straightforward task. Apart from issues generic to all information systems, GIS developers face specific challenges in geographical data handling and user interface design.

In many GIS applications, complexity and difficulty in system design and development result from the number and variety of data and users involved. Web-based GIS systems are expected to serve, often concurrently, a large number of users involved, often from different locations, and seeking access to many different combinations of datasets from a range of data custodians. Transformation, analysis and visualization of geographical data in both vector and raster format demand heavy computing and network usages. For better decision making, useful information needs to be delivered to users efficiently. This requires both a proper GIS planning as well as collaborative efforts from engineers in the fields of communication, hardware and software.

Geographical data have three key components: spatial, temporal and thematic. The spatial component geocodes where geographical features (or phenomena or processes) occur; the thematic component describes what kind of geographical features (or phenomena or processes) occur; and the temporal component indicate when the represented geographical features (or phenomena or processes) were current. Users interact with geographical data based on theme, location and/or time. With the limited web-browser space, careful user interface design is required. This will define the level of usability of the system and these determine much of the impact on decision making processes. Support for display of different formats of information, such as tables, summaries, maps and timeline, should be provided for. Provision of user input tools would enable flexible access to all aspects of the data and “cloud sourcing”.

Very common complaints from GIS users are about user interfaces mention confusion and poorly organized layout (Morris, 2006). User needs hold the key in the system development

when addressing these issues. Based on the study of user needs for a particular flooding disaster management system (see Chapter Two), this chapter focuses on two key issues related to web-based GIS. One is about optimization of user queries through proper indexing strategies, and the other is about specific considerations on the user interface.

4.1.3. Three-tier web-based GIS architecture

Web-based systems based on the three-tier architecture (Figure 4-1) can provide a useful technological platform for disaster and emergency management. The three-tier architecture includes the database tier, application tier and the user interface tier.

The user interface tier is a standard Web browser, supporting users in terms of data querying, content browsing and information representation. These functions are built upon standard web technologies such as HTML (Hyper Text Markup Language), KML (Keyhole Markup Language), WMS (Web Map Service), WCS (Web Coverage Service), WFS (Web Feature Service), and others (Bugs et al., 2009, Plewe, 1997).

In the application tier, functions are grouped into three modules, namely geoprocessing and transformation, modeling and analysis, and feature editing and management. Geoprocessing and transformation module consists of a series of tools for handling, piping and transformation of geographical data in different formats. Feature editing and management is another important module that data administrators use for data maintenance purposes. Modeling and analysis module is a group of functions for various kinds of analyses i.e. spatial analysis, geostatistical analysis, temporal analysis and other standard database analysis.

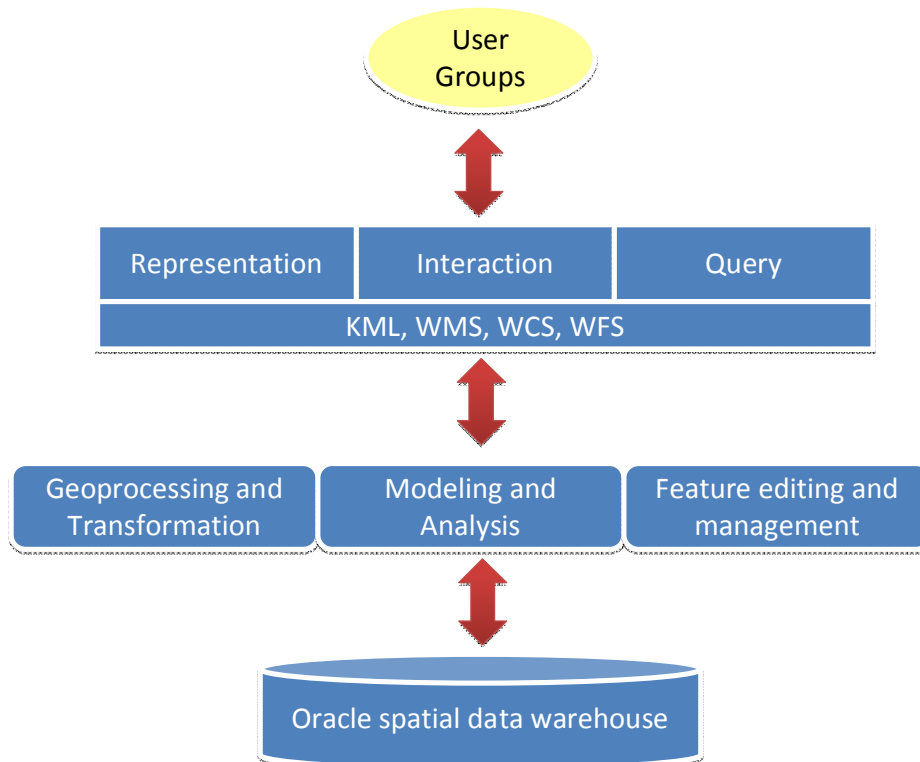


Figure 4-1 Three tiers Web-based GIS architecture

4.1.4. Web 2.0

The Web technology is fast evolving into its second generation, Web 2.0. This is a major shift in ITS and it is imposing its impact on information systems and users in many ways (Bugs et al., 2009). Simply speaking, Web 2.0 based GIS means more robust network infrastructure allowing more advanced interactions between information systems and the users: users are enabled not only to retrieve information from the Internet but more to make contributions (Goodchild, 2007, Rinner et al., 2008).

Web 2.0 is designed with greater bandwidth so as to enable the handling of much more information than was possible with Web 1.0. Having the capacity for transferring large amount of GIS data across the Internet does not mean that system designers can push all information to users without much consideration. Information overload will make things worse not better. Users are now concerned more with the usability of the data they are now able to obtain from the web (2.0) based systems. This also brings about challenges in user interface design. More complicated interfaces are needed to access and present large volume of data for improving and

speeding up the decision-making processes. Information needs are often task-driven. An intelligent user interface should help the user to find and access the required information and report or present the information in useful formats.

The Web 2.0 platform and technologies offer the public great opportunities to contribute to the system and consequently to the processes of decision-making. The “cloud sourced” data will populate the system much quicker than ever before. Web 2.0 based GIS will give the public more flexible access to the information and enable policy makers to collect and summarize the public opinion in a more efficient, natural and more representative manner.

4.2. Information query

4.2.1. Spatial and temporal queries

In spatio-temporal database systems, the geometries and attributes of objects are time-stamped, to reflect real world entities’ changes in positions and shapes with time, and to allow users to query the databases about these changes. The changes of flood extends during a flood event, and the different flood extents for different flood events, for examples, are important to flood studies that underpinning many flood emergency and floodplain management plans.

Derivation of approaches to querying changes in object positions and shapes is not as easy as first thought. A simple approach could be to highlight changes from one time or during a period of time. The more complicated queries can be to find out the percentages of increased or decreased areas or lengths. A typical example for movements of objects in flooding events is the moving flood front. Moreover, changes in either positions or shapes may have influence on other objects in terms of attributes or spatial relations. The damage to a park increases when the flood extent covers larger areas of the park, for example. Modeling for a more complicated and thereby probably more realistic scenario must accommodate concurrent changes occurring in both position and shape so that the dynamic nature of damages to the park might be monitored (Figure 4-2).

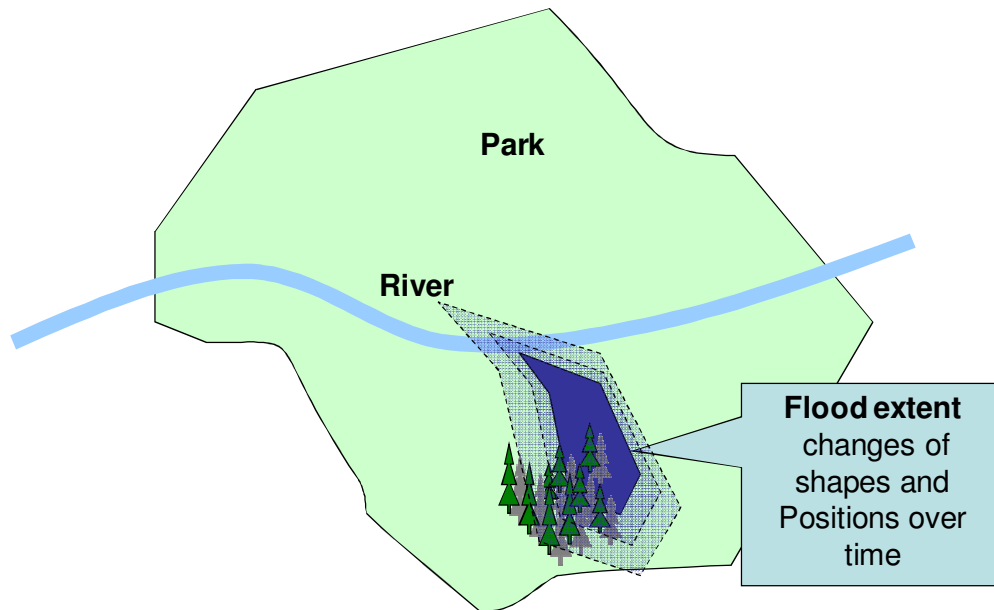


Figure 4-2 Changing flood extent imposing dynamic damages to a park

The changes in entities' positions and shapes may be represented either as discrete objects or as continuous fields, or both, depending on the query purpose. Proper representation of changing phenomena calls for a number of considerations, including the nature of the phenomena, the scale of the representation, the use of the representation, and computing overhead for data management and use. For the purpose of flood study, for example, certain aspects of the flood events, such as the moving flood front, need to be recorded in greater spatial-temporal details, compared to data on land use patterns and damaged properties. High resolution temporal data imposes great increases in the size of data set and also computing load for processing and analyzing the data sets.

The changes of objects stored in databases can be classified as historical recorded changes and /or as modeled or predicted changes. The historical data records the information related to events of the past. The modeled or predicted changes normally derived from the historical and contextual data, also need to be included in the database for better decision making. Special considerations are needed in both database and user interface designs to avoid possible confusions between these two groups of data to the end-users.

There are two general types of user query addressed to spatio-temporal information. Questions on situations at specific timestamps, which may have happened or have been predicted, are often

asked during the decision making process. For example, a particular householder may want to know what happened to his/her property in a major flooding event that occurred 10 years ago. The other type of user query relates to questions on information over a period of time. A researcher, for instance, studying the spatial behavior of a flood event, would focus on the whole process of changes in flood extents.

4.2.2. Spatial and temporal SQL language

The term SQL refers to Structured Query Language. SQL is supported by most of the modern database management systems, including MySQL, Oracle, IBM DB2, and MS SQL Server (Corral et al., 2004). SQL is designed for effective handling, accessing and maintaining of data. SQL has a near half century history and the latest version is SQL2008.

The standard SQL consists of a number of key functions.

- Data type: The type declarations of columns in the table include such functions as CHAR, BIT, INTEGER, and DATE.
- Data definition: Fundamental functions for the definition of data (table, view and index) structures include CREATE, ALTER and DROP.
- Data manipulation: Functions for data manipulation include INSERT, UPDATE and DELETE.
- Query: SELECT is the most frequently used querying function, has become a very powerful database query tool, and has a large number of keywords and complexity structures.

The following SQL statement is an example of the join query. In this query, the properties along the selected roads are firstly selected; then another selection is based on the previous result to list all the properties within the area of interests; finally, the average loss of these properties due to a flood event are calculated.

```
SELECT Area.name, AVG (Join_table.lost_value)

FROM (SELECT * FROM Property JOIN Road_of_Interests
```

```

ON MEET (Road_of_Interests.shape = Property. shape)) AS Join_table

INNER JOIN Area_of_Interests ON (Area_of_Interests.name =
Property.area)

```

SQL is not designed for spatial and temporal query. Therefore, spatial and temporal extensions to SQL have been developed recently.

There are a number of spatial SQL extensions such as SQL/OGIS, PSQL, QL/G, Spatial SQL, GeoSQL, CSQL, GEOQL, and SQL/SDA. Most of these spatial extensions have similar spatial query supports for topological operation and spatial analysis. Examples of topological operators include EQUAL, DISJOINT, INTERSECT, TOUCH, CROSS, WITHIN, CONTAINS and OVERLAP (Figure 4-3). Examples of spatial analysis functions include DISTANCE ANALYSIS, BUFFER, INTERSECTION, UNION, and others.

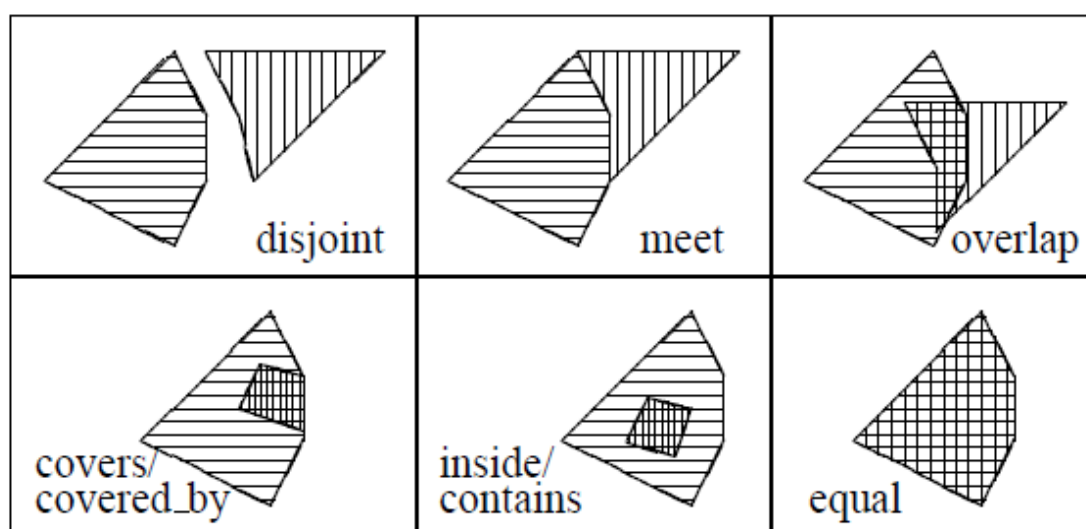


Figure 4-3 Topological operators in OGIS (Egenhofer, 1994)

Example 1: list road names which are not flooded in 2009

```

SELECT road.name

FROM road, flood_extend_2009

WHERE Disjoint (road.shape, flood_extend.shape) = 1

```

Example 2: list properties within 100 year flooding zone

```
SELECT property.name  
  
FROM property, 100_year_flood_zone  
  
WHERE overlay (property.shape, 100_year_flood_zone.shape) = 1
```

Example 3: property lost in one flooding event in all suburbs

```
SELECT property.cost  
  
FROM property, flood_event_A  
  
WHERE overlay (property.shape, flood_event_A.shape) = 1  
  
GROUP by propety.suburbs
```

There are also many temporal data models and related SQL extensions developed for handling temporal information and temporal queries. Examples include SQL/TP, TQuel, SQL^T, IXSQL, TSQL2, HSQL, and SQL/Temporal. These models use timestamping technique to store temporal information as point-based, element-based or interval-based (Carvalho et al., 2006, Cho and Chung, 2007).

Temporal query languages support temporal topological operators. Figure 4-4 shows a example of the temporal topological relationship (Peuquet, 1994). In flood studies, for example, temporal queries may be issued by researchers who want to determine the temporal relations between flooding events and rainy seasons, or retrieve the properties flooded at a specific time during a flood event.








RELATION	SYMBOL	X	Y
X before Y	<		
X equal Y	=		
X meets Y	m		
X overlaps Y	o		
X during Y	d		
X starts Y	s		
X ends Y	e		

Figure 4-4 Temporal topological relationships (Peuquet, 1994)

Example 1: list the water spots that its water levels are higher than safe level during a flood event

```
SELECT water_spot.name
FROM water_spot, flood_event
WHERE water_spot.level > safe level AND
DURING (water_sport.time, flood_event.time)
```

Example 2: list properties that are flooded at the beginning of flood event

```
SELECT property.name
FROM property, flood_extend
WHERE Starts (property.flooded_time, flood_extend.time) = 1
```

4.2.3. Spatial and temporal indexing

Indexing is a key database technique used for optimizing data access and retrieval. The basic principle of indexing is to create data indexes which can be quickly accessed without going

through all the records in a database. Theoretically, indexes can be created on all information (columns) but creating and updating indexes itself require lots of computing resources. Therefore, indexes need to be created thoughtfully and strategically. This requires comprehensive studies on the user needs and data sets. This section will focus on the spatial and temporal indexing techniques.

A typical index table contains two columns, one is the indexed value and the other is the address of the record in the data table. More complicated index table is organized in a tree structure for large data sets. The most popular one is the R-tree developed by Guttman (Mondal et al., 2005, Shekhar and Chawla, 2003). Spatial objects (point, line and polygon) are simplified by their minimum bounding rectangle (MBR), as shown in Figure 4-5. Figure 4-6 is the R-tree of Figure 4.5 which presents a group of spatial objects. R-tree can be multiple-level and have leaf nodes and non-leaf nodes. Non-leaf nodes contain information of their child notes while the leaf nodes point to the data locations. R-tree searching is very fast.

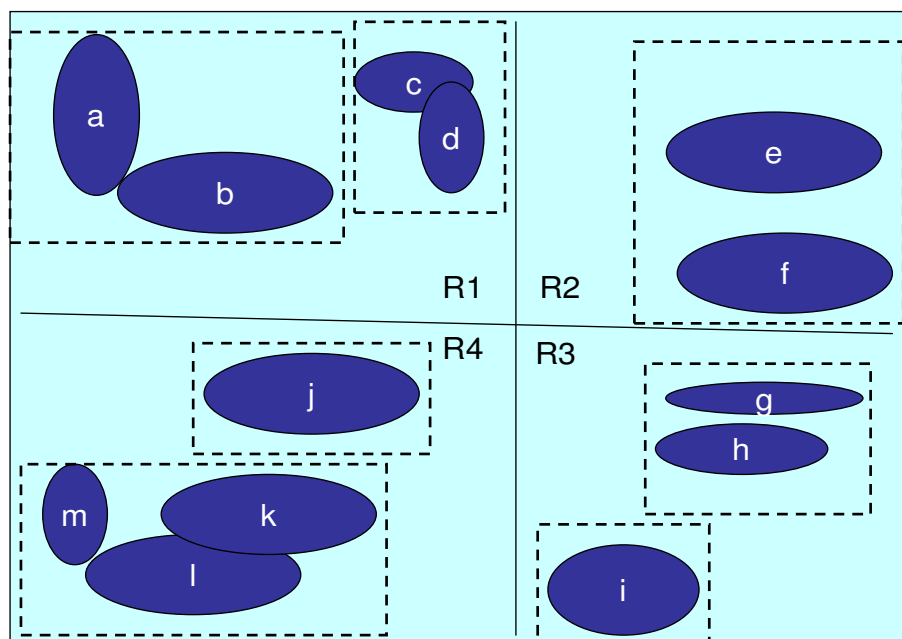


Figure 4-5 Spatial objects

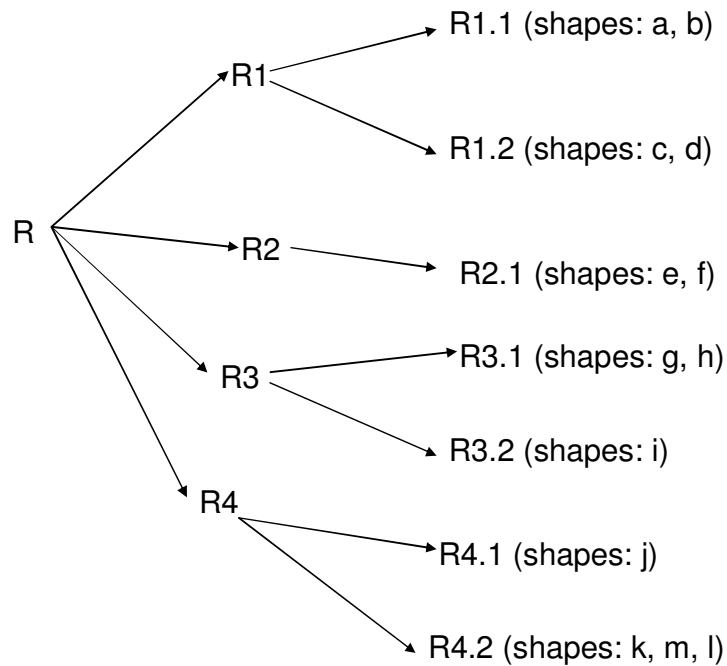


Figure 4-6 R-tree indexes of spatial objects in Figure 4-5

There are a number of variants of R-tree, such as R* tree, R+ tree and HR-tree (Eo et al., 2006, Güting, 1994, Mondal et al., 2005). In Web-based GIS systems, spatial features can be updated frequently. Therefore indexes need to be updated frequently. The key of HR-tree is to define the sibling nodes in a clear structure and relation. Algorithms that calculate the clusters of each leaf nodes are very important to the performance of HR-tree (Eo et al., 2006, Wang et al., 2005). Dynamic HR-tree is suitable for the dynamic applications where the database is updated by different users at different time. HR-tree can be updated quickly because of the clear structure of sibling nodes. This is very important in the web-based GIS system with a large spatial database.

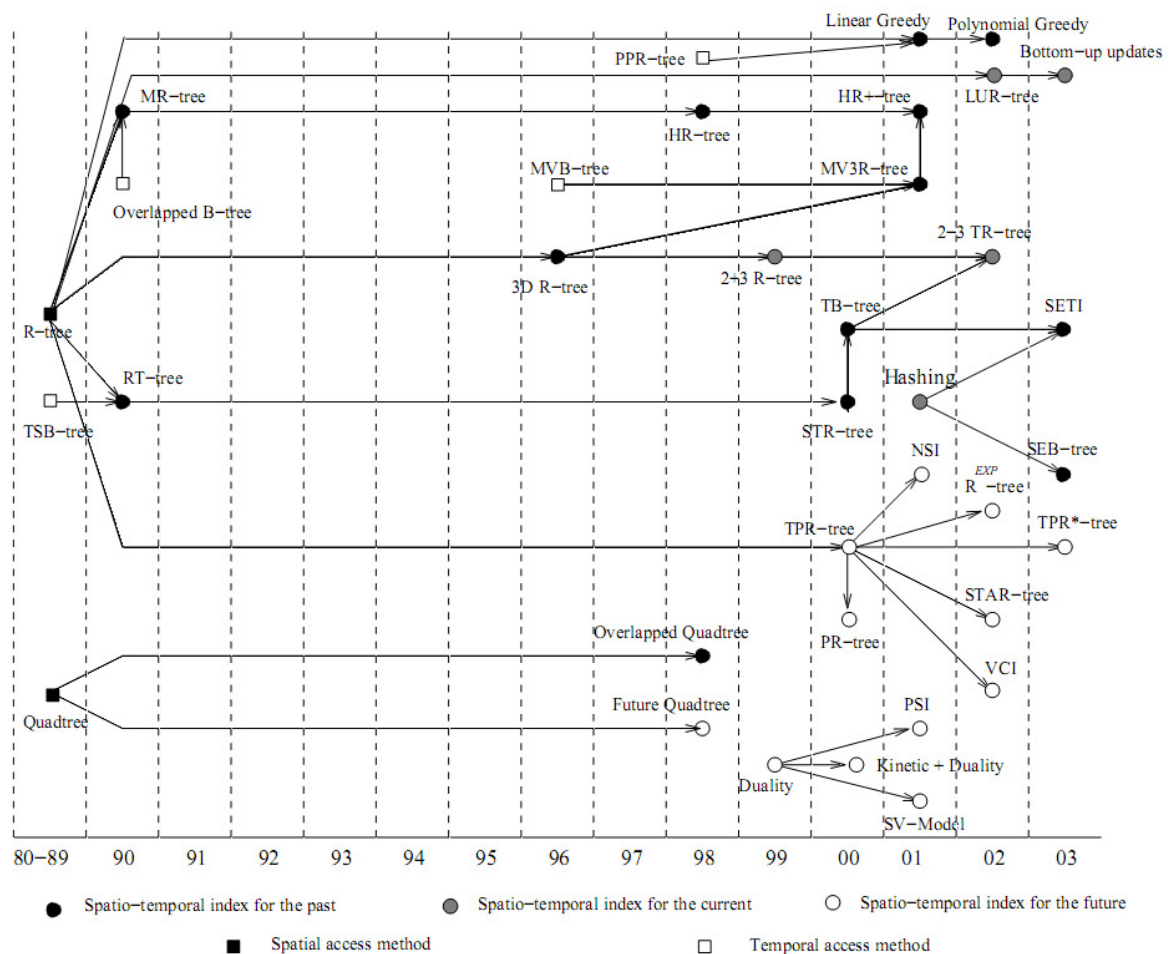


Figure 4-7 Summary of spatio-temporal indexing techniques (Mokbel et al., 2003)

Indexing is very critical to database performance. Spatio-temporal GIS systems demand more robust indexing system for speeding up the query of their high dimensional data (Back et al., 2010). Many researchers have been done in this area based on the R-tree technique which is supported by most database management systems available on the market. Figure 4-7 presents clearly the development of spatio-temporal indexing techniques (Mokbel et al., 2003), and indicators. The current focus on GIS indexing is in the spatial domain. It is hard to say whether the temporal domain is less important or more complicated than the spatial domain. However, the temporal aspect of information is becoming more and more important as the information era progresses.

MV3D-tree is one of the well-developed indexing method specifically developed for spatio-temporal databases (Yao and Papadias, 2001). The MV3D-tree is a combination of multi-version

R-tree (MVR-tree) and 3D R-tree. Timestamp query is supported as each of the tree leaves contains the timestamp. This technique also supports interval query by combining the structures of both MVR-tree and 3D R-tree. The basic idea is that the MV3D-tree contains multiple R-trees for the different time. The MV3D-tree design supports extensive data model analysis thus optimizing benefits of applying each technique and facilitating the creation of unique customized combination of queries.

4.3. Interactive and ad hoc reporting

In general, the reporting process transforms accessible data into meaningful business intelligence (BI), which can be used to identify problems, spot trends, and support decision making. In addition to spatial information representation, organization, access and analysis, report augmentations by means of maps, tables and charts are invaluable to decision and policy makers. In combination, these reporting approaches can display effectively the spatial relationships and patterns of geographical feature, summaries attribute information about geographic features in a tabular format and present the relationships and trends revealed by the analysis in charts.

Comparing with information querying, reporting provides to the users, based on their domain of interest, more focused, customized, salient information. As having been discussed in chapter two, the great variety of different user groups, together refer to a range of different information needs and domains of interests. For example, government agencies, NGOs, researchers, general public and local communities, need information on different aspects of disasters, such as data on the hazards, data on the exposure and vulnerability of the elements at risk, and data that provide a context where in the interactions between the hazards and the elements at risk are unfolding event by event. To facilitate the reporting functionalities across multiple user groups, and to provide conventional personalized reports based on different domains of interest, interactive reporting and *ad hoc* reporting techniques have been developed in recent years.

4.3.1. Interactive reporting

The concept of interactive reporting is to provide one user-friendly interface with a series of Business Intelligence tools that allows users to produce maps and generate reports based on their own interests.

A map is visually very effective in using mathematical principles and graphical elements to present and communicate geographical information, including the locations, extents and spatial relationships among all sorts of geographical features in the mapped area. Interactive maps are maps in digital form, which can be accessed by multiple users simultaneously through computer networking by using Web browsers. Compared to traditional paper maps, interactive maps have many advantages as listed below.

- Interactive maps provide broader spatial information distribution. Compared to physical distribution of paper maps, interactive maps are web-based and accessible via the Internet or Intranet depending on the business scenario. Utilizing the power of networks, interactive maps can deliver spatial information easily and efficiently to a wide variety of people at a very low cost, and allow multiple users to access the interactive maps anytime, anywhere. Therefore, interactive map can communicate much more information to wider audiences in less time than can a static map.
- Assuming implementation of active data maintenance, interactive maps provide users with the most up-to-date information. An interactive map does not contain the data associated with the map, but sources the data from elsewhere, such as a database on the server. This allows the underlying data to be updated independently of the map, and the current data can be immediately delivered to users through the computer network ready for customized/user-based map composition.
- Interactive maps provide users with specialized tools for retrieving information. With specialized tools, users can effectively and efficiently access and retrieve spatial data using interactive maps based on the needs. Since users can display the map in different ways and query the map for different kinds of information, a single interactive map can communicate much more information in less time than can a static map.

Interactive maps allow user to manipulate the map display and conduct operations on the map to get the information using a set of specialized tools such as:

- Layer on / off – function to turn on or turn off layers. Turning layer on/ off is a very common functionality in interactive mapping application, which allow user to choose the visible map layers in the map. It is especially important when there are many layers available in the map, by turning on and off the map layers user can control the map content based on their own preference.
- Pan – navigation function to allow user navigate around the map at the current map scale. Panning is a very basic function in mapping applications which allows user to navigate to the area of their own interest.
- Zoom in and out – navigation function to allow user zoom in to see more detailed map or zoom out to a larger extent. Zooming in/ out is a very fundamental function that allow user to navigate to specific map extent at their own preferred map scale.
- Identify feature – function to help user identify a feature by displaying attribute data of the feature. By using identify tool, user can click on a feature in the map, and a list of one or more records (polygons, lines or points and corresponding attributes) associated at that location will be automatically displayed. This tool is important for user to understand and retrieve the attribute data of spatial feature at their concerned location.
- Measure distance – tool for user to measure the equivalent real world distance between map locations. Measure tool is useful for user to get to know the actual size of a spatial feature or actual distance between locations in the map.
- Select – tool that allows user to select one or multiple spatial feature on the map and display the corresponding attribute data of the selected feature. Comparing with identify tool which is based on the map location user clicked on, select tool allow user to select multiple feature in the map with different shape of polygons, such as rectangular, circle, or other shapes created by user on the map, and select tool retrieves attribute data of all the selected features.
- Find – function that allows user to allocate spatial features based the attribute data. In contract with select tool, find tool is used to search spatial features based on their attribute data. The function will perform a searching operation based on user defined criteria, then highlight all the matching spatial features and display attribute data as result.

- Buffer – buffer tool creates buffer polygons around specified features and select all the features from user specified layer within the buffer. Buffer tool is important and helpful in locating features with a certain distance of selected object. For example, if a property is damaged by flood, buffer tool can be used to find the all the shelters within 10 km of that property.
- Spatial overlay – spatial tool to overlay two spatial layers and return the spatial features from one layer within selected features of the other layer. This is very important tool for user to conduct spatial queries, such as selecting all the properties affected by a flood event by applying spatial overlay on property layer over the maximum flood extent.
- Bookmark - User can create bookmarks of the areas of interests and use these bookmarks to navigate to their pre-defined map extent directly. This function is very handy if the user has specific interest area and need to navigate to these areas regularly.
- Print maps - export a map file for publication purposes or a hard-copy plot that can be used for display in documentations or reports.

Most interactive maps are created using GIS publishing software, installed as application on a server, and distributed to users over the Intranet or Internet. Users then use a Web browser as the viewer to access these interactive maps. The specialized tools embedded in the interactive maps facilitate the access and use of spatial information by allowing the interaction between user and application, but the level of interaction that determines if the tools will be included in the map should be based on user requirements and needs. To support data retrieval and analysis on flood events, for example, a set of interactive map tools with custom reporting mechanisms will be discussed further in chapter five based on the user needs analysis conducted in Chapter 2.

4.3.2. Ad hoc reporting

Many reporting applications are built on top of very large databases. They allow access only via a pre-programmed and ‘optimized’ menu that supports limited query and report functionalities over a pre-defined and restricted data scheme. On the contrary, ad hoc reporting allows users to create specific, customized reports based on their own needs via a user-friendly interface (Amin and Goldstein, 2008, Emergency Management Australia, 1999b).

As an important Business Intelligence utility, ad hoc reporting is, for many reasons, gaining popularity in database reporting applications. First, using the ad hoc reporting approach, the user can build the report query and define the output fields based on their own interests in a manner which requires no understanding of the underlying data schema or the SQL applied to the database. Compared with traditional reporting methods, ad hoc reporting can provide great flexibility to the user and meet different needs of individuals from different user groups. Moreover, contrasting with traditional reports which are standardized and programmed, ad hoc reports are automatically produced on an ‘as needed’ basis. As a result, developers do not need to constantly tweak reports with different criteria to meet a user requirement. This will reduce the work of redevelopment and ease the application maintenance and update processes. Finally, ad hoc reporting can be integrated with other technologies and programming interfaces to create easily comprehensible charts and diagrams, aggregated tables or maps. Therefore, high quality reports with additional elements can be created using ad hoc reporting tools, and these reports can be very helpful for users intent upon gaining a better understanding of the situations or scenarios reported. Considering the broad user groups and different user needs for information on natural disasters, ad hoc reporting will be the most appropriate and effective approach for establishing such an information system.

As ad hoc reporting is widely accepted and adopted, more and more business-intelligent tools that support ad hoc reporting development have become available either from the database vendors (e.g. Business Intelligence Discoverer from Oracle and Report Builder from Microsoft SQL Server) or from open source reporting platforms (e.g. Jasper and Pentaho). Because both Oracle Discoverer and SQL Server Report Builder are bundled with the underlying database and there are costing issues involved, the two leading open source ad hoc reporting tools, Jasper and Pentaho, are investigated further here. Both of these two platforms support ad hoc reporting design, viewer development, and underlying OLAP (Online Analytical Processing). Their relative strengths and foci are summarized in Table 4-1. It is clear that Jasper focuses more on reporting and analysis while Pentaho is better in data transformation, workflow and enterprise integration. Considering the development perspective, Jasper is regarded as the more suitable tool for developing ad hoc reporting functionalities for the case study presented in chapter five.

Table 4-1 Comparison of two reporting systems

Reporting tools	Report features	Database supported	Output	Useability	Paid version
Jasper	Excellent reporting and analysis features. Great presentations,	Support major RDMS via JDBC, file based database.	PDF, XML, HTML, CSV, XLS, RTF and TXT	Easy user interface and good documentation	Available, enhanced web UI
Pentaho	Powerful data integration, online analysis tools and data mining	Support major RDMS via JDBC, file based database.	HTML, PDF, XLS, RTF, XML and CSV	WYSIWYG report creation, report Wizard	Available, with a number of selected modules

4.4. Summary

This chapter starts with an introductory account of the nature of Web-based information access. This was followed by a discussion of the advantages of a Web-based GIS system. It is found that the web-based online system 1) offers better solutions for information sharing to a large range of organization users and the public, 2) provides cross-platform capability via the standard Web protocols, 3) has a low-cost in system maintenance, and 4) presents users with an easy and friendly user interface. However, there are still some key issues and limitations related to the technologies in GIS applications. The developers of the Web-based GIS systems need pay extra attentions on the large volume of data handling and to user interface design. These have great influence on the performance and usability of the system. The three-tier framework of Web-based GIS has been introduced: database tier, application tier and user interface tier. The latest Web 2.0 technologies and their impacts to next generation Web-based GIS system have been explained. ICT development is one of the major drivers of GIS technologies and system design.

The second part of this chapter focused on the spatio-temporal queries in the context of flooding information system design. The key query languages available have been reviewed and studied. These languages are extensions of SQL standards. Examples of the queries are given. Indexing technologies are critical in database management and this is more important for GIS applications because a spatio-temporal database has larger data volume and complexity in general, and serves a larger number of users across platforms. A variety of spatial, temporal and spatio-temporal

indexing techniques based on the popular R-tree (supported by all current database systems) has been identified as offering the best indexing technique in this context.

Internet is now providing the most popular and convenient platform for publication, acquisition and sharing of information. Endowed with a friendly user interface and querying and reporting operations, a web based GIS system can manage and distribute information on natural disasters in a much more dynamic and interactive manner than can alternative ICT approaches. With an interactive map interface, and ad hoc reporting tools, users will be able to carry out different searching and reporting operations on both spatial and attribute data.

5. CASE STUDY: RESULTS AND DISCUSSIONS

5.1. Study area and source datasets

Flooding is one of the most damaging hazards in Australia: average annual cost of flooding have been exceeding \$400 million in recent years (Liu, 2005). Floods impose substantial economic, social and environmental costs on flood-labile communities through injury and death, direct damage to buildings and critical infrastructures, and indirect losses due to disruption of economic activity.

This study investigates the scope for spatio-temporal representation, data modeling, and data accessing and reporting of disasters by using data relating to flood events in the Gardiners Creek catchment, a sub-catchment of the Yarra watershed (Figure 5-1 and Figure 5-1).

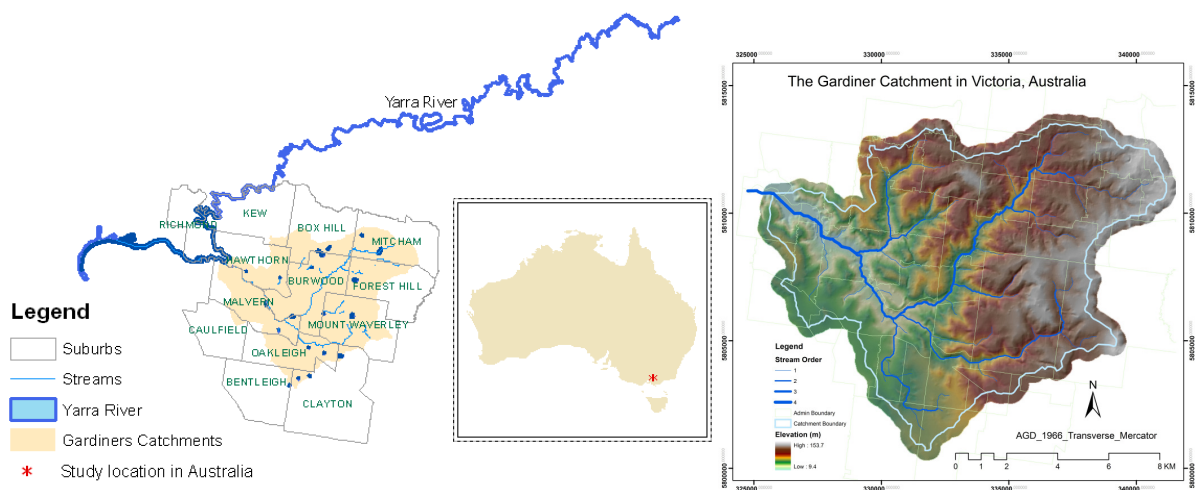


Figure 5-1 The case study area: Gardiners Creek Catchment of the Yarra River Watershed, and related suburbs in Melbourne, Victoria, Australia



Period	Rainfall (mm)		Flow (ML/day)			Level (m)	
Monthly	total	max	min	mean	max	min	mean
30/11/2009	103.00	3377.073	1.241	93.127	1.880	0.020	0.154
31/12/2009	52.80	1739.083	1.241	42.907	1.220	0.020	0.090
31/01/2010	31.80	1599.229	0.468	31.679	1.160	0.010	0.068
28/02/2010	32.80	2661.056	0.468	26.964	1.600	0.010	0.067
31/03/2010	77.20	6654.783	1.241	79.468	3.050	0.020	0.120
30/04/2010	31.40	2338.451	1.241	35.238	1.470	0.020	0.113
31/05/2010	31.80	740.200	2.739	31.534	0.720	0.030	0.097
30/06/2010	71.00	2437.141	4.867	88.449	1.510	0.040	0.147
31/07/2010	26.60	878.950	2.739	34.350	0.830	0.030	0.112
31/08/2010	63.60	2387.617	7.492	92.042	1.490	0.050	0.165
30/09/2010	48.00	1061.436	4.867	51.413	0.920	0.040	0.121
31/10/2010	133.00	6654.783	4.867	169.054	3.050	0.040	0.173
Summary	703.00	6654.783	0.468	64.685	3.050	0.010	0.119

Figure 5-2 Total Rainfalls, Instantaneous Flow Rates and Instantaneous Levels Recorded at the Gardiner Station for the Last 12 Months (Source: Melbourne Water. <http://www.melbournewater.com.au/>).

Yarra River in Victoria is the major river running through the City of Melbourne, and Gardiner Creek is one of the principal tributaries of the Yarra River which drains the inner south-eastern suburbs of Melbourne. This catchment is predominantly urban and consists of Gardiners Creek, Scotchmans and Damper creeks. The total area of Gardiner Creek catchment is approximately 115 km², covering 44 localities in 6 local government areas (LGAs). The population density in this area is about 2000,-3,000 persons/km² (Sokolov and Black, 1996).

The total rainfalls, instantaneous flow rates and instantaneous levels recorded at the Gardiner rainfall and level station for the last 12 months are shown in Figure 5-2. Major Gardiners Creek Catchment flood events (year 1955-2005) are selected as primary inputs in this case study. Based on the discussion of data model in Chapter Three, the datasets are categorized into four thematic groups including flood data, hydrographical data, and contextual data. As shown in Table 5-1, the datasets used in this study and sources of these datasets have been listed.

Table 5-1 Datasets used in the case study

Thematic Group	Theme	Data Description	Format	Source
Flood	Flood features	Spot Level	Shapefile	Melbourne Water
		Flood Extent	Shapefile	
		Overland Flow Extent	Shapefile	
	Flood information	Flood Event	DBF	EMA
		Flood Damage	DBF	
Hydrology	Channel	Profile Line	Shapefile	Melbourne
		Cross Section	Shapefile	

	Network	Cross Section Point	Shapefile	Water
		Hydro Junction	Shapefile	
		Hydro edge	Shapefile	
	Drainage	Drainage Point	Shapefile	
		Drainage Line	Shapefile	
		Catchment	Shapefile	
	Hydrography	Dam	Shapefile	
		Structure	Shapefile	
		Hydro Line	Shapefile	
		Water body	Shapefile	
Context	Infrastructure	Roads	Shapefile	VicRoads
		Road Infrastructure	Shapefile	
		Railway Station	Shapefile	
		Railway	Shapefile	
		Utility Point	Shapefile	
		Utility Line	Shapefile	
	Property	Address Point	Shapefile	DSE
		Property	Shapefile	
		Point Of Interest	Shapefile	
	Administrative Area	Suburb	Shapefile	
		LGA	Shapefile	
		State Assembly	Shapefile	
	Topology	Contour	Shapefile	
		DEM	Raster	
	Census	Census data	shapefile	
	Imagery	Aerial Photo	Imagery	
		Satellite photo	Imagery	

The hydrographical and flood data are mainly acquired from Melbourne Water (<http://www.melbournewater.com.au>), except that the DEM is created using the contour data (with 1 m contour interval) from DSE. Because the historical flood extents and other spatial datasets are not available, water spot level, flood extents and overland extent simulated for 5 year, 20 year, 50 year and 100 year flood events using DEM and hydrological prediction models are used to demonstrate the prototype system. The contextual data that represents the physical world is obtained from DSE (Department of Sustainability and Environment), including administration boundaries, hydrographical features, properties, infrastructures and utilities, etc.

Information on these major flood events is acquired from the disaster database on EMA (Emergency Management Australia) website as a list, and separated into two dbf files: one

contains the flood event information including event name, start date and end date, duration, magnitude, intensity and other factors of the event; the other one includes the damage information of this flood, such as human loss, property damage, cost figures and etc. EventID is a unique numerical field that links two parts of information for the same flood event.

5.2. Database Development

5.2.1. Data organisation

Given the intended flood-related applications, the existing representations of the source datasets, and the logical data model discussed in chapter three, the datasets listed in Table 5-1 have been represented and organized into three thematic data collections, including flood data, hydrological data, and contextual data. Data models for each of these data collections will be discussed in the rest of this section in terms of the database objects, relationships between tables, table structures, data constraints and indexes.

The flood data collection represents flood event information with flood features and flood attributes (Figure 5-3). The spatial characteristics of the flood events are represented by the spatial datasets, Flood Extent, Flood Overland Flow Extent and Spot Level, and the flood impact is represented by the non-spatial Flood event and Flood Damage tables. Each flood event has a unique ID (EventID). The Flood Event table contains essential information for each flood event, such as the title, the start and end dates, duration, intensity and magnitude of the flood event, and uses the EventID as the primary key to link the flood event with other related features and attributes. The Flood Damage table contains the damage information of a flood event, such as the human losses, property damages, and other cost figures. The relationship between Flood Event and Flood Damage is one to one, and these two tables are linked with the EventID field. The Flood Extent and Overland Flow Extent table contains the spatial features relevant to documenting a flood event. With timestamps, the flood extents and overland flow extents are organized in a temporal dimension which can be used to represent the spatio-temporal changes of a flood event. Each flood event has multiple extent features based on timestamps; therefore the relationship between Flood Event table and these flood extent tables is one to many. Spot Level data contain water depths information at a water spot location at a particular time, which

provides the water depth data of the flood. With a DEM and proper spatial model the Spot Level data can be used to estimate the water depth of the flood and create a 3D simulation of the event.

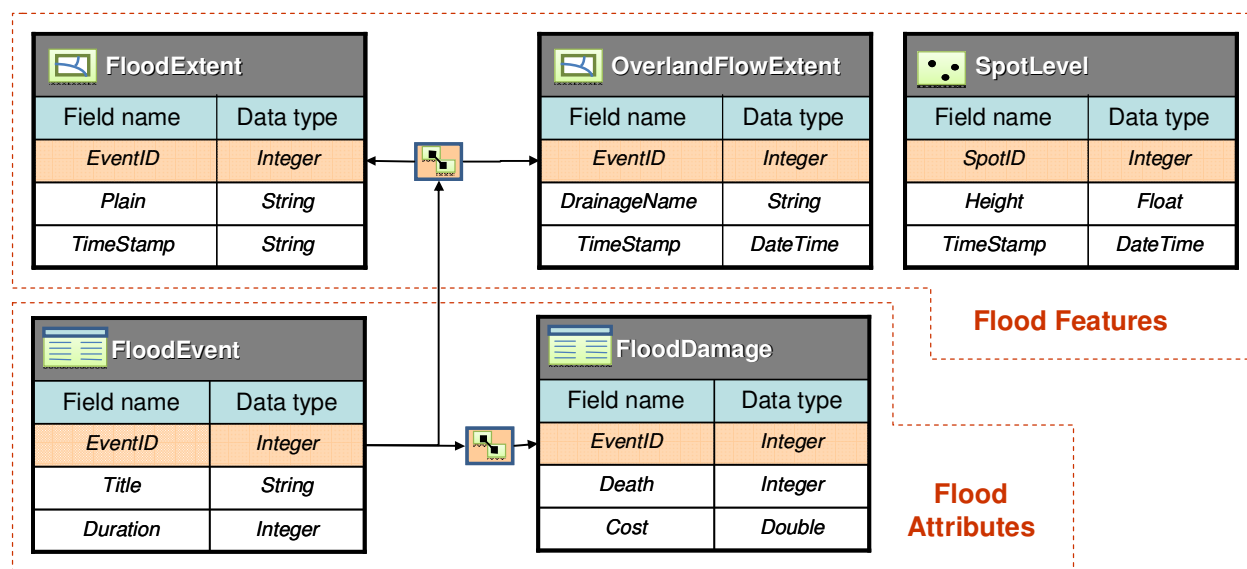


Figure 5-3 The flood data collection

The hydrological data collection includes four feature datasets: Channel, Network, Drainage and Hydrography (Figure 5-4). Channel features represent the 3-D profile and cross-section of stream channels using cross section point, cross section and profile line. Network features represent the geometric shape and topological connectivity of the surface water features of the landscape, such as flow lines, shorelines, and points located at the ends of flow segments and at other strategic locations on the flow network, using a connected network of hydro edge and hydro junction. Drainage features represent standard drainage areas (usually administratively selected and named after the principal streams and rivers of a region), elementary drainage areas (often defined by subdividing the landscape according to a set of physical rules), centerlines of flow paths (usually derived from a DEM using a GIS), and the outlets or pour points of these selected and defined drainage areas or watershed boundaries. The data is assembled using derived or digitized drainage point, line and polygon. The hydrographic feature class includes other associated hydrographic features such as water body, water lines, dams and other water structures. The relationships among these feature classes as well as the relating keys are shown in Figure 5-4.

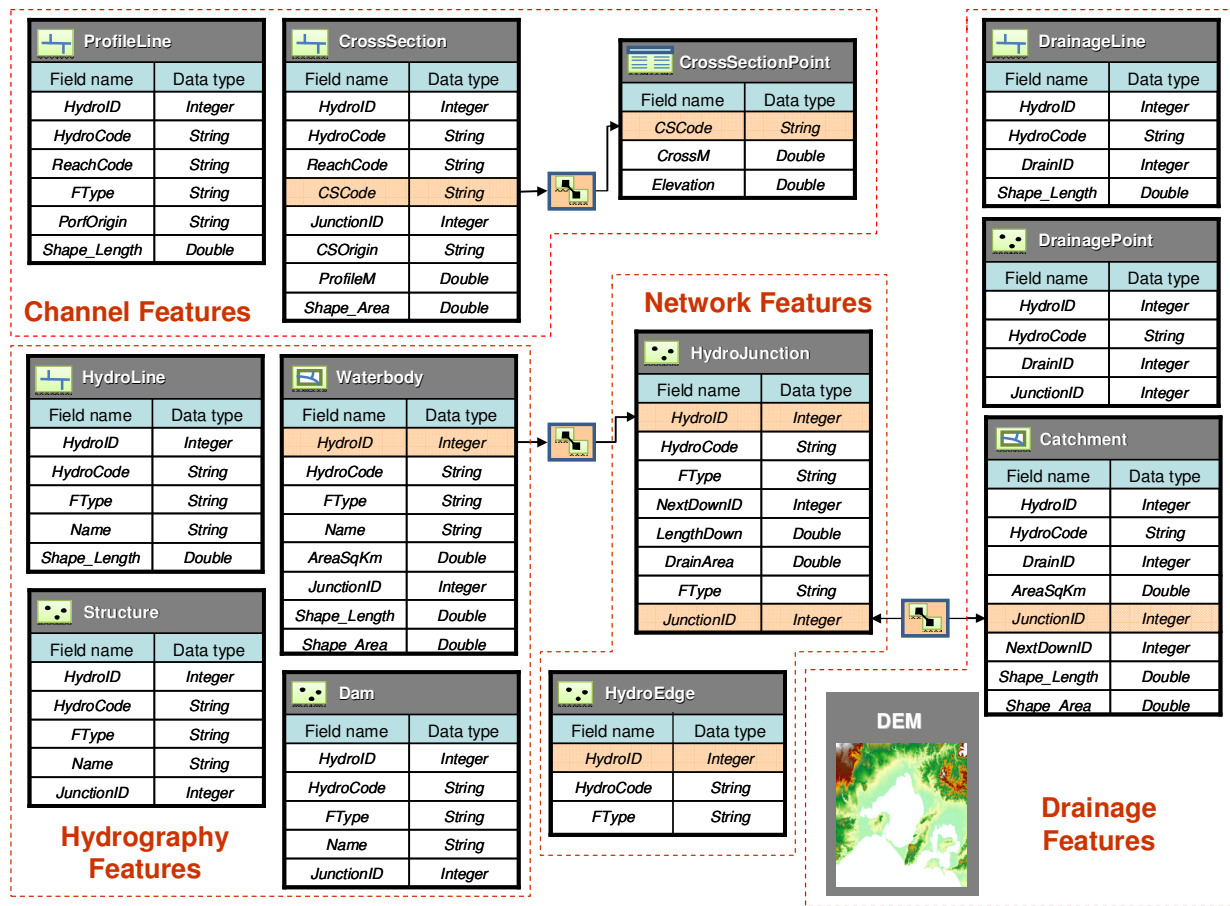


Figure 5-4 The hydrological data collection

The contextual data collection provides the geographical context wherein the flood event and associated hydrological process unfolds. When a flood strikes on these contextual geographical features, also known in emergency management as the Elements at Risk, the flood disaster occurred. To estimate the impact of the flood disaster, the spatial relationships between these contextual features and the flood extent need to be established with topological and spatial operations, e.g. by spatial overlay. In this application, contextual data is divided into four categories, including property features, infrastructure features, topographical features and administrative areas. As shown in Figure 5-5, property features include address points, point of interest, and property parcels; infrastructure features consist of roads, road infrastructures, railway lines, railway stations, utility point sand utility lines; topographical features include 1 meter, 5 meter, 20 meter contour lines and aerial photos; and administrative features include LGA (Local Government Areas), suburb and state assembly boundaries. .

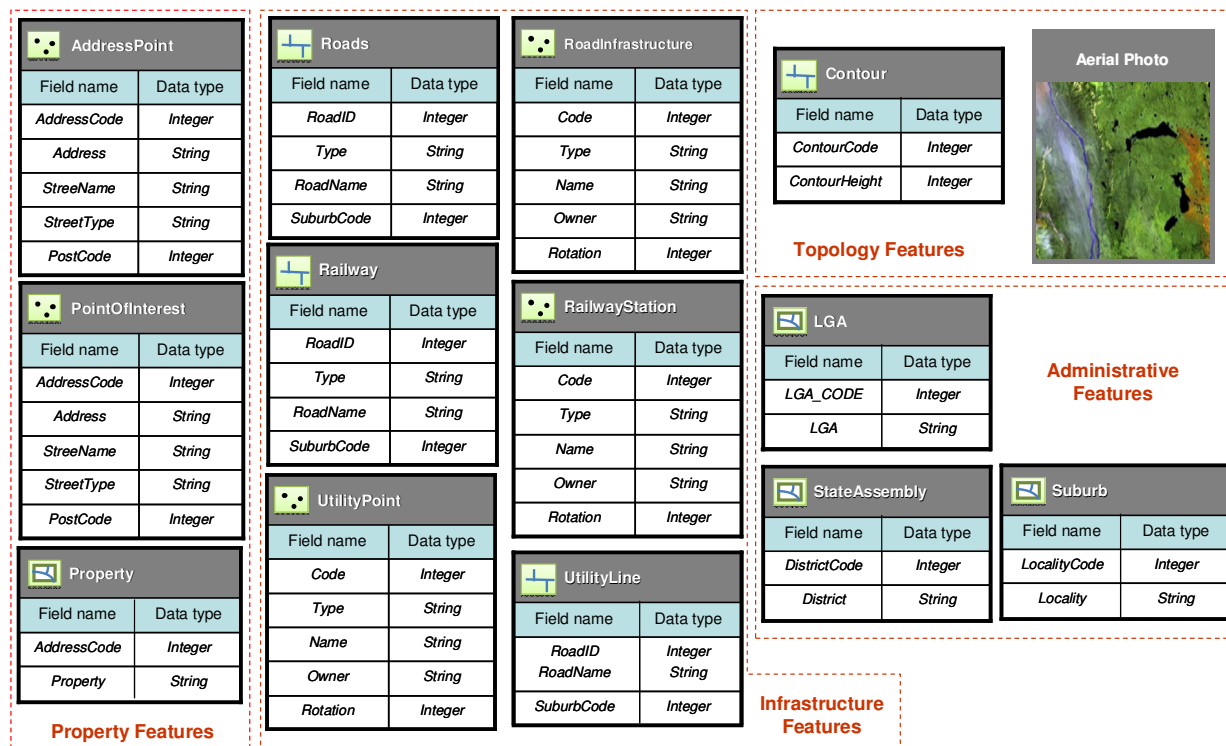


Figure 5-5 The contextual data collection

5.2.2. Database creation

One of the key considerations in creating a database is scalability. It is a key consideration because of the need to cope with the probability that analysis will involve extraordinarily large data assemblages. In this study, the DBMS and its configuration are scoped in such a way that it is capable of future expansion and enhancement so that enormous data volume involved in documenting the different types of natural disasters recorded over tens or even hundreds of years can be analyzed. As a result, the Oracle database 10g with its Oracle Spatial component is selected as the DBMS in this study.

Oracle Spatial is a separately-licensed extension of the Oracle Database. It supports managing geographic and location-data in a native type within an Oracle database. Oracle Spatial is chosen for two main reasons: First, Oracle is the leading DBMS which is capable of handling extremely large collections of data and it supports distributed databases that may be essential for future development. Second, Oracle Spatial supports operators and functions via the SQL interface for performing area-of-interest queries, spatial join queries, and other spatial analysis

operations, which normally require complex programming codes when implemented in other systems. With Oracle Spatial, spatial queries can be easily performed using the SQL statement, and hence is facilitated the spatial data analysis, and the operational performance and ease the application development is enhanced.

Oracle Spatial database is constructed with a set of object data types and type methods, while operators, functions and procedures can be used on top of them to perform assorted processes. The core data type for Oracle Spatial is "SDO_GEOMETRY", which can be used much like any other Oracle data type in tables and procedural code. Oracle Spatial supports uniform spatial data storage: geometry is stored as an object with type of SDO_GEOMETRY in tables, which can be points as SDO_POINT_TYPE, element information array as SDO_ELEM_INFO_ARRAY or coordinate array as SDO_ORDINATE_ARRAY.

Spatial indexing, which is important in facilitating spatial data access and retrieval, is also supported in Oracle spatial. R-tree indexing (discussed in Chapter Four) is used in Oracle Spatial, and the spatial R-tree index can index spatial data in up to four dimensions. Spatial indexes can be created and maintained by using basic DDL (data definition language) and DML (data manipulation language) statements. The metadata geometry that describes the dimensions, boundaries and tolerance is also supported by Oracle Spatial. The ALL_SDO_GEOM_METADATA table contains metadata information for all spatial tables, and for different users Oracle can create respective USER_SDO_GEOM_METADATA views to maintain the metadata associated with the specific user.

In this study, Oracle Database with Oracle Spatial extension was installed on an individual server as the data server, which is separated from the application server in the system architecture. After the installation, three types of users are created in Oracle database with different database administration and security privileges. The first user group is for system administrators, and this group includes the default users created during Oracle installation. This user group has the full privileges to the database including start up/shut down a database, create/backup/recover a database, create/remove tablespaces, create/remove tables etc. The second user group is for data maintenance, such as data update and editing tables. This user group has been granted with limited privileges including SELECT, INSERT, and DELETE objects. The ArcSDE (which will be discussed in next section) users with editing permission,

belong to this user group. The last user group is for data access only, which is used for external users or applications accessing and querying the database. This user group has minimal privileges with only the SELECT permission. ArcSDE viewer users (refer to section 5.2.3) is part of this user group, and the username and password used for building the database connection in the web application belongs to this group as well.

Only one instance is created in Oracle in the current implementation that focuses on flood disasters. However for future development, multiple instances can be created to serve data of different disaster type. According to the logical data model discussed in Chapter Three, the process that have been carried out in this database development include the following steps: creating tablespaces, creating schema, creating tables, uploading data, and creating indexes.

Based on the thematic themes in the data model, the database is logically divided into three tablespaces, which are FLOOD_DATA, HYDO_DATA, and CONTEXT_DATA. A tablespace is a logical storage unit within an Oracle database, which defines the physical portion of the database used to allocate data. The data objects within a tablespace are often related. Oracle stores data logically in tablespaces and physically in data files associated with the corresponding tablespace. Using multiple tablespaces provides more flexibility in performing database operations and enables better overall availability. With multiple tablespaces, data can be separated for different users from data dictionary to reduce I/O contention. If a tablespace must be taken offline, the other tablespaces would not be affected, and individual tablespaces can be backed up separately as well.

To create the HYDRO_DATA tablespace, for example, the following SQL statement is used:

```
CREATE TABLESPACE hydro_data(  
    logging  
    datafile '/dbf1/ hydro_data.dbf'  
    size 32m  
    autoextend on  
    next 32m maxsize 2048m  
    extent management local  
);
```

Basically, the SQL statement created a tablespace with name “hydro_data” with the following parameters: logging is enabled on this tablespace; the physical data storage file is located at %dbf1/ hydro_data.dbf; the initial size of the tablespace is 32MB, and the size will be automatically increased by 32MB when the tablespace is full.

Creating schema In Oracle, a schema corresponds to a collection of data objects like tables, views, and stored procedures. A schema is owned by a database user and has the same name as that user. Schema objects are logical structures created by users to contain or reference data. Schema objects include structures like tables, views, and indexes, which can be created and modified using the SQL. Just for clarification, there is no logical relationship between tablespace and schema: one tablespace can be used for multiple schemas, while one schema can own data objects belonging to multiple tablespaces. By having multiple users and corresponding schemas, database can be logically divided into different data collections and the schema owner has the privileges to control all the schema objects and give permissions to other users.

It is usually the case that the data sources of different themes in the disaster management system are maintained by different government departments or other stakeholders. Accordingly it is necessary to provide for creation of different users and schemas so as to maintain the data ownerships and accessibilities. Three users are created in this implementation to manage data objects of different themes, including FLOOD, HYDRO and CONTEXT. Each schema is assigned to the corresponding tablespace created in the previous step for data management purposes.

To create the HYDRO schema, for example, the following code (below) is used for creating the user and setting up the owner permission:

```
CREATE USER hyrdo IDENTIFIED BY password
        DEFAULT TABLESPACE hyrdo_data
        TEMPORARY TABLESPACE temp
        QUOTA UNLIMITED ON users;

GRANT CONNECT, CREATE TABLE TO hydro;
```

After the schema is created, the read permission is granted to users in the viewer group, for example, WEB_USER, which is used for connection between web applications to the database. The following code is used, for example, to create an application user for the web application to access the schema.

```
CREATE USER web_user IDENTIFIED BY password  
  
    DEFAULT TABLESPACE users  
  
    TEMPORARY TABLESPACE temp;  
  
  
GRANT CONNECT TO web_user;
```

Creating tables Table is the basic unit of logical data storage in an Oracle database. After schemas are created, the schema user can create tables to hold the actual data. In this study, there are two types of data: spatial and non-spatial data. The spatial data tables are created with the SDO_GEOMETRY column, while non-spatial data tables are created without the SDO_GEOMETRY column. As shown in Table 5-2, tables belongs to different themes are created by the corresponding users inside the corresponding tablespace.

Table 5-3 Data themes and tables

Schema	Theme	Table name	Feature Type
Flood	Flood Features	SpotLevel	Point
		FloodExtent	Polygon
		OverlandFlowExtent	Polygon
	Flood Information	FloodEvent	Text
		FloodDamage	Text
Hydro	Channel	ProfileLine	Line
		CrossSection	Line
		CrossSectionPoint	Point
	Network	HydroJunction	Point
		HydroEdge	Line
		HydroEdge	Line
	Drainage	DrainagePoint	Point
		DrainageLine	Line
		Catchment	Polygon
		DEM	Raster
	Hydrography	Dam	Point
		Structure	Point
		HydroLine	Line
		Waterbody	Polygon
Context	Infrastructure	Roads	Line
		RoadInfrastructure	Points
		RailwayStation	Point
		Railway	Line
		UtilityPoint	Point
		UtilityLine	Line
	Property	AddressPoint	Point
		Property	Polygon
		PointOfInterest	Point
	Administrative Area	Suburb	Polygon
		LGA	Polygon
		StateAssembly	Polygon
	Topography	Contour	Line
		HillShade	Raster
		AerialPhoto	Imagery

As an example, the following SQL statement is used to create the drainage point table within the hydro schema and store it in the hydro_data tablespace:

```
CONN hyrdo/password
```

```
CREATE TABLE hydro.drainagepoint(  
    objectid NUMBER PRIMARY KEY,  
    hydroid NUMBER NOT NULL,  
    hydrocode VARCHAR2(32),  
    drainageid NUMBER NOT NULL,  
    junctionid NUMBER NOT NULL,  
    shape MDSYS.SDO_GEOMETRY,  
    CONSTRAINT drainagepoint_pk PRIMARY KEY (objectid),  
) TABLESPACE hydro_data;
```

Uploading data In this study, the spatial datasets are sourced mainly in ESRI shapefile format. After the tables are created, a number of tools can be used to load ESRI shapefile data into the Oracle Spatial table, including Geometry's Spatial Console, OGR's sdo2sdo, MapBuilder, shp2sdo etc. Oracle Spatial using Oracle's pre-processors shp2sdo, a free command line tool that converts ESRI Shapefiles to corresponding Oracle Spatial tables and associated metadata, is used to perform the data upload process.

The basic command used to load the drainage_point shapefile into a drainage-point spatial table, for example, is as follows:

```
shp2sdo.exe -o drainage_point drainagepoint -g geom -d  
-x (-180,180) -y (-90,90) -s 8307 -t 0.5 -v
```

1. Creating indexes – a spatial index must be created on the tables for an efficient access to the data. As addressed before, spatial index can be an R-tree index or a quad-tree index. The following code is used to create a spatial index on the column of type SDO_GEOMETRY.

```
CREATE INDEX hydro.drgPt_Index ON  
    hydro.drainagepoint (shape)  
    INDEXTYPE IS MDSYS.SPATIAL_INDEX;
```

5.2.3. Database access

To enable efficient access to any large volume of spatial data stored in a RDBMS such as Oracle, ESRI has developed the ArcSDE (ARC Spatial Database Engine) as a RDBMS gateway to store, retrieve and handle spatial data in RDBMS and provides the spatial datasets access for different applications. In this study, ArcSDE is selected as the data engine server for accessing and managing geospatial data stored in Oracle according to the following considerations.

Firstly, ArcSDE supports spatial data management in a number of RDBMS, including IBM DB2, Informix, Microsoft SQL Server, Oracle and PostgreSQL (supported in 9.3 version), and enables robust multi-user read and write access and flexible controllability. Using ArcSDE, spatial data can be managed seamlessly, users do not need to deal with the particulars of the RDBMS, and the spatial datasets can be accessed and manipulated by multiple users (up to the RDBMS limits) simultaneously. With ArcSDE, the same spatial data can be consumed in multiple applications and at the same time can be updated by a number of database administrators. As a result, ArcSDE can enhance data management performance within Oracle Spatial and supports concurrent multiple data access.

Secondly, ArcSDE makes the spatial datasets within DBMS easily accessible for the ESRI Desktop products such as ArcMap and GIS Web Service products such as ArcGIS Server and ArcIMS. In the latest version, ArcSDE 9.3, good integrity and development potentials between ArcGIS Server and ArcSDE have been established. Therefore, by using ArcSDE, spatial data and attributes in Oracle can be easily accessed with GIS applications such as the ArcGIS Server, enabling the fast development of web-based GIS applications.

Thirdly, ArcSDE supports comprehensive geographic data modelling and ensures a high-integrity of spatial data storage in RDBMS. Using ArcSDE on top of a RDBMS ensures well-formed geometric integrity of all spatial data, including vector and raster geometries, coordinates, topologies, networks, annotation, metadata, geoprocessing models, maps, layers, and so on. This is critical for the collection of super-large datasets such as dense lidar point clouds and high resolution precipitation raster data involved in many flood emergency management applications.

Lastly, ArcSDE supports data management work flows in GIS, such as multi-user editing, history, checkout/check-in, and loosely coupled replication, that relies on long transactions and versioning. This is essential and vital from a database administration perspective, especially for dynamically growing databases such as the databases on flood disasters.

To minimise the CPU cycles and memory usage on the database server, ArcSDE is installed on a separate server from Oracle Spatial database in this implementation. In order to achieve this separate installation, the Oracle client was installed on the server where the ArcSDE component is installed.

As addressed in the previous section, Oracle Spatial is selected as the DBMS in this study. However, Oracle SDO geometry is not the standard data type that ArcSDE supports. To leverage strength from both Oracle Spatial and ArcSDE, the ArcSDE has to be specially configured to support Oracle Spatial in this implementation. ArcSDE DEFAULTS configuration keyword has been changed to SDO_GEOMETRY for the GEOMETRY_STORAGE parameter. With this configuration, spatial data is stored as Oracle Spatial (SDO geometry) and made available to ArcSDE. Hence, the implementation combines the power of the Oracle SQL interface and all the Oracle Spatial procedures and packages, access and power to maintain the stored spatial data via the ArcSDE and ArcGIS Server for web-based data publication.

Three different user accounts GIS_ADMIN, GIS_EDITOR and GIS_VIEWER are created with different privileges. GIS_ADMIN is an account for the administrator that has full privileges to the ArcSDE data server and the underlying Oracle database. It is used by the database administrator to manage the database and perform administrative tasks, such as creating backup files, performing a data compression operation, and to grant or revoke user privileges. GIS_EDITOR is the account for editors, who has read/write permission to all the feature classes and attribute tables. System editor can access Oracle database using this account to insert, delete, update and select data, create spatial and attribute indexes, or perform other editing operations. GIS_VIEWER is an account established for accessing the datasets via the web GIS applications. With the read only privilege, user can only perform SELECT operations in the geodatabase. Using the GIS_VIEWER account in the web-based applications ensures that data will be accessed only for viewing and querying purposes by the internet users. This will prevent unexpected access and data manipulation, and hence increase the database security.

5.3. User interface

The user interface is one of the most crucial components influencing the acceptance of a software system (Güttler et al., 2001). The interaction between the user and a web-based GIS system relies on a graphical user interface (GUI), which may be developed using software platforms provided by GIS vendors. In recent years, there has been an explosion of interactive mapping applications on the web, such as Google Maps and Bing Maps, and more and more platforms have become available for publishing geographic information on the web, including GeoBase, Smallworld's SIAS or GSS, MapInfo's MapXtreme or PlanAcess or Stratus Connect, Cadcorp's GeognoSIS, Intergraph's GeoMedia WebMap (TM), ESRI's ArcIMS and ArcGIS Server, Autodesk's Mapguide, SeaTrails' AtlasAlive, ObjectFX's Web Mapping Tools and the open source MapServer or GeoServer. In this study, ArcGIS Server is selected to publish the GIS resources on natural disasters across the Web.

ArcGIS Server is a widely used commercial GIS software package developed by ESRI, which allows GIS resources, such as maps, address locators and customized tools, to be shared across local networks or the Internet. ArcGIS Server provides Web-oriented spatial data services, and these services can be consumed by web browsers, mobile devices and desktop systems with flexibility of access and interaction. ArcGIS Server is selected for two main reasons: from the server management perspective, as a server technology, ArcGIS server manages data centrally. It supports multiple users, and is able to provide clients with the most up-to-date information. From a developer's perspective, ArcGIS Server supports OGC and W3C interoperability standards such as, WMS, WFS, WFS-T, WCS and KML (see discussion in Chapter 4).

As shown in Figure 5-6, the workflow of developing a web application using ArcGIS Server with Javascript API (Application Programming Interface) involves five basic steps:

1. Build map MXDs (ArcGIS map document format) and create Geoprocessing models;
2. Publish GIS services using these map resources on ArcGIS Server;
3. Find the services and the parameters of using these services in the Service Directory;
4. Edit HTML/Javascript to consume services in Web application; and
5. Review and test functionalities of the application using the Web browser.

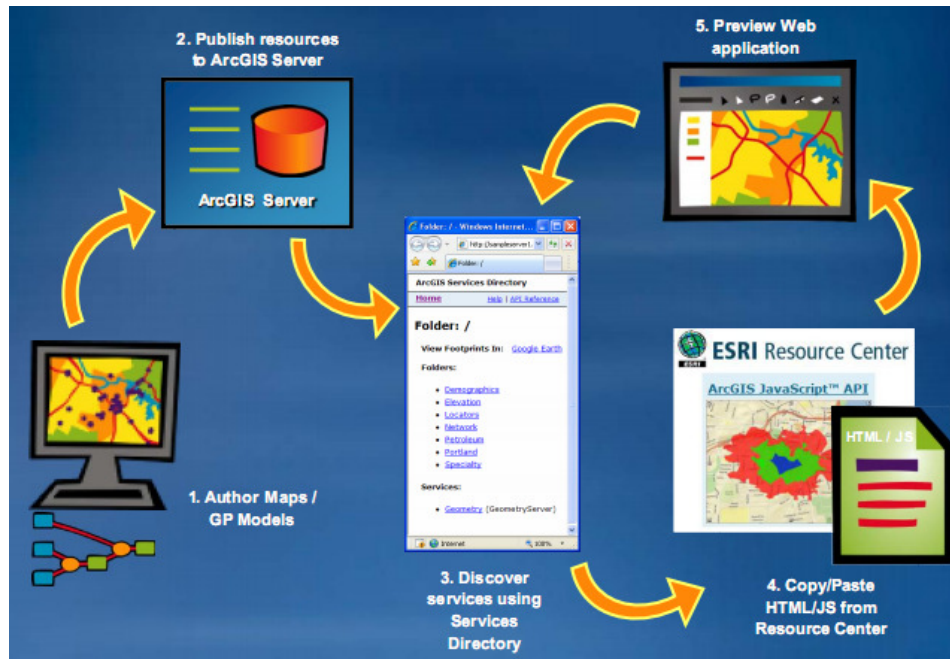


Figure 5-6 Workflow of creating ArcGIS Server web mapping applications (ESRI)

These five steps can be grouped into two major development phases: creating GIS services (including steps 1 and 2), and building user interface (including steps 3, 4 and 5). A GIS service is a representation of a GIS resource that a server distributes to the user via a network; while a user interface is a browser-based interface with customized toolboxes for accessing and interacting with the map service. The detailed implementation of publishing GIS services and building web applications will be discussed in the following sections.

5.3.1. GIS services

A GIS service represents a GIS resource such as map, globe, locator, or geodatabase connection. The services are hosted on the server and accessible by client applications. ArcGIS Server stores the resource, hosts the service, and performs GIS operation or processes, while users can consume the services within a Web browser or custom application by sending requests to the server for a specified service so as to receive a result in a common specified format (images or text). Therefore, GIS services can ease the resources sharing across clients without the need to install specialized GIS software. Publishing a GIS resource as a service is the key to making that resource available to the users.

ArcGIS Server can publish different types of services, including map service, image service, geocoding service, geoprocessing service, geometry service, globe service and so on. Based on the data model and the user needs for analysis outcomes (discussed in previous chapters), a set of services have been designed to enable data access and to support query and reporting tasks in reference to disaster data. The table below summarizes the services created for this study and the purposes of creating them (Table 5-4).

Table 5-4 GIS services developed in the case study and their purposes

Service Type	Service Name	Purposes
Map services	Flood Data	Provide access to the contents of flooding event map layers.
	Hydro Data	Provides access to the contents of hydrology map layers.
	Contextual Data	Provides access to the contents of contextual data layers.
	Base map	Provides access to the background map.
Image services	Aerial Photos	Provides access to aerial photo imagery.
Geometry services	Geometry	Helps applications perform geometric calculations such as buffering, simplifying, calculating areas and lengths, and projecting.
Geoprocessing services	Identify feature	Provides access to toolbox that returns attribute data by clicking on the actual feature.
	Select feature	Provide access to toolbox that allow user to select features by different shapes, such as line, rectangle, circle, and polygon.
	Find feature(s)	Provide access to toolbox that used to find feature based on the attribute value.
	Buffer	Provide access to buffer toolbox that create buffer around the specified feature(s).
	Spatial overlay	Provide access to toolbox that performs spatial overlay operation on specified layer to get the features within user selected feature.

During the implementation, some special configurations have been made to optimize the performance of the system:

Firstly, as shown in table above, multiple map services are created in this application to support publication of maps data scheme by data scheme rather than imposing reliance on the one (integrated) map service. Compared with an integrated map service, the multiple map services are more efficient and able to handle concurrent requests faster by having different instances of SOC (Server Object Containers) in the ArcGIS Server environment: one for each different map service.

Secondly, “Base map” map service, which represents the backdrop of the study area, has been cached in this application. Map caching is a very effective way to reduce the response time in loading the base maps. Map caching creates tiled images of the entire map at several specified scales, and stores the image tiles on the hard disk. When a map image is requested, the server can then distribute the image straight away without re-drawing it. It's much quicker to command the ArcGIS Server to return a cached image than to draw the map each time there is a request. Base map is the map service which will be accessed most times, and it contains relatively complex layers. Accordingly caching this map service will improve the system performance and reduce the response time of map retrieval.

Lastly, specialized toolboxes are built in this application to generate geoprocessing services that can be used in web applications to conduct spatial operations listed in Table 5-4. Using the buffer tool, for example, a geoprocessing service that allows the user to buffer a point feature can be created with the following procedure:

1. Create a tool share folder on the server, add a new toolbox “BufferPoints” in ArcToolbox, and create a point feature class schema in ArcCatalog.
2. Create the geoprocessing service as a model (Figure 5-7) using model builder, and ensure the model generates a polygon buffer around the input point feature with a specified buffer size.
3. Publish the geoprocessing service by right-clicking BufferPoints in the ArcToolbox menu and clicking “Publish to ArcGIS Server”.

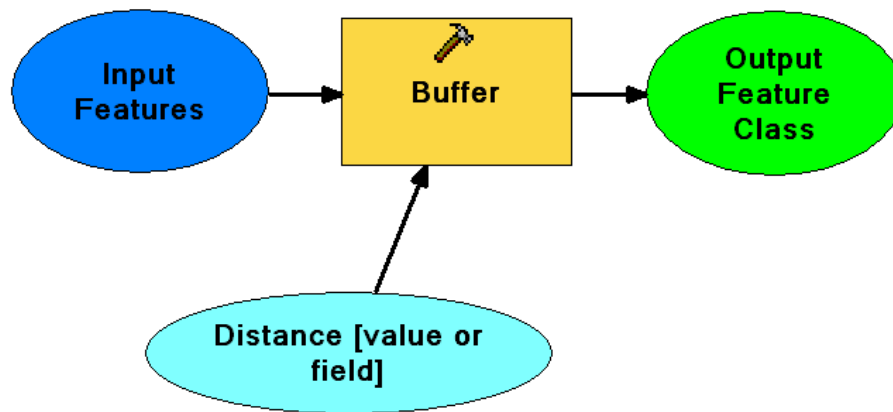


Figure 5-7 Buffer point model

5.3.2. Web application

Instead of using the default web application created by the ArcGIS Server Manager, it is a sample JavaScript viewer developed by ESRI SampleViewerTeam that is adopted in this study. The sample viewer is a Web2.0 style user interface template that integrates some of the core capabilities of the ArcGIS Platform. By taking advantage of the strengths of JavaScript and an open source JavaScript toolkit, Dojo, the JavaScript Viewer can be used to construct an advanced dynamic web UI. With modifications to the configuration files and the source code, application developers can use the sample viewer as a base template to develop advanced GIS web applications using ArcGIS JavaScript API, HTML, Dojo widgets and utilities.

In contrast to traditional web applications, the JavaScript Viewer has an object-oriented JavaScript programming model, which enables interaction between objects and the ArcGIS Server services. As shown in Figure 5-8, the JavaScript Viewer application goes through a five stage sequence:

1. ArcGIS JavaScript API (Dojo) is loaded in the HTML page and the page is then parsed into the client's browser.
2. The JavaScript Viewer application loads the configuration XML file and applies it. The configuration file contains information on the map server, and initialises the needed service and the settings of menu and tools of the viewer.

3. Based on the configuration file, the map layers are loaded from ArcGIS Servers via the application which constructs and displays the menu controller with branding information from the config XML file.
4. The Widget manager loads the Widget class files which are specified in the config XML file.
5. The users interact with the Widgets to interact with the ArcGIS Server to perform specified operations to the map and underlying data.

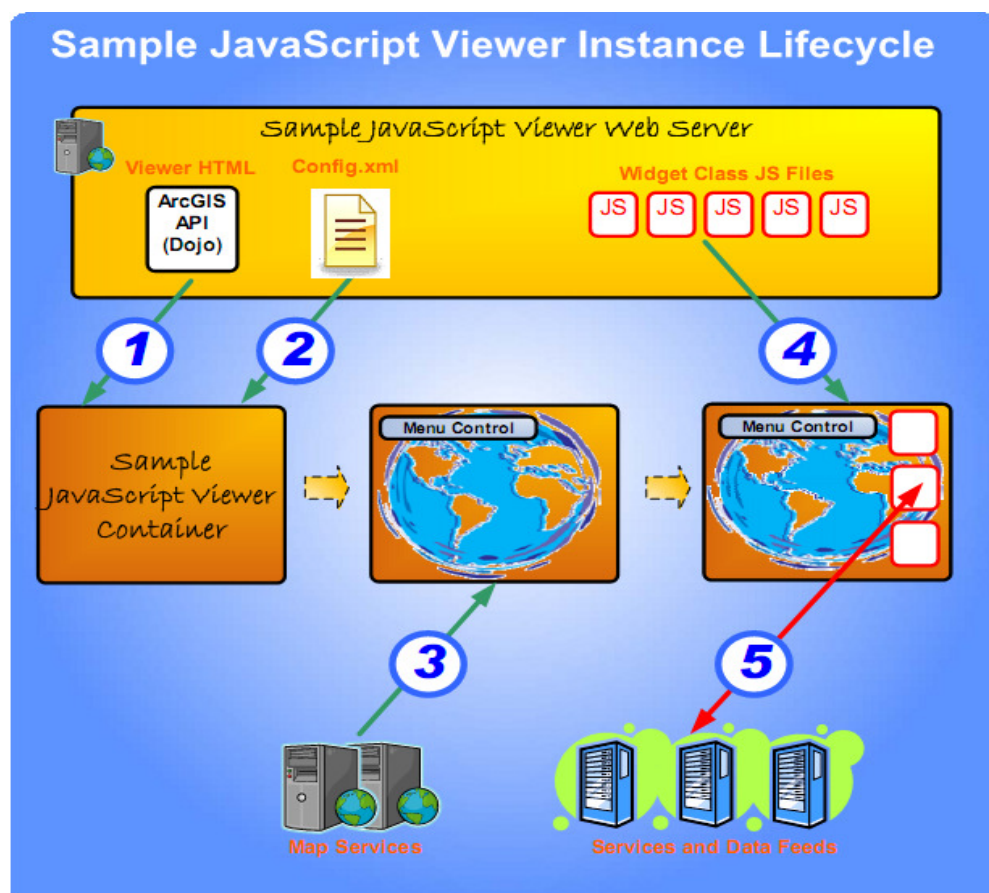


Figure 5-8 Interaction between the viewer and the service

A Widget is a single JavaScript file, which encapsulates a set of isolated and focused business logic so allowing users to perform a specified task. In a service oriented environment, a Widget represents a service or an orchestration of services with which users can execute a business function. A Widget is not only visually interactive with the user, but also could connect from the

ArcGIS Server to server-side resources such as Map Services. Therefore, widgets are used in this application to develop different tools for query and reporting.

During the web interface development, there are two major development phases: configuration of page components and map services, and development of widgets.

The configuration phase modifies the page components and defines the map services. In the JSViewer directory, the main configuration file, config.xml, is modified to define the page components such as the menu objects, the map services, the tools and widgets under different menus.

There are three main steps in modifying the configuration file. Firstly, the web page title and the main menu are defined with XML code. As shown in Figure 5-9, the title of the web application is named as “Gardiner Creek Catchment Viewer”, which is defined using “<title>” XML tags in the code. The main menu includes four parts – map, navigation, tools and help. “<Menu>” XML tags are used to define these menu objects, and assign each menu with a pointed image logo.

```
<userinterface>
  <banner>visible</banner>
  <title>gardiners creek catchment viewer</title>
  <subtitle>yanxi zhou 2009</subtitle>
  <logo>assets/images/logo.png</logo>
  <stylesheet></stylesheet>
  <menus>
    <menu id="menumap" visible="true" icon="assets/images/icons/i_globe.png">map</menu>
    <menu id="menunav" visible="true" icon="assets/images/icons/i_nav.png">navigation</menu>
    <menu id="menuwidgets" visible="true" icon="assets/images/icons/i_widget.png">tools</menu>
    <menu id="menuhelp" visible="true" icon="assets/images/icons/i_help.png">help</menu>
  </menus>
</userinterface>
```

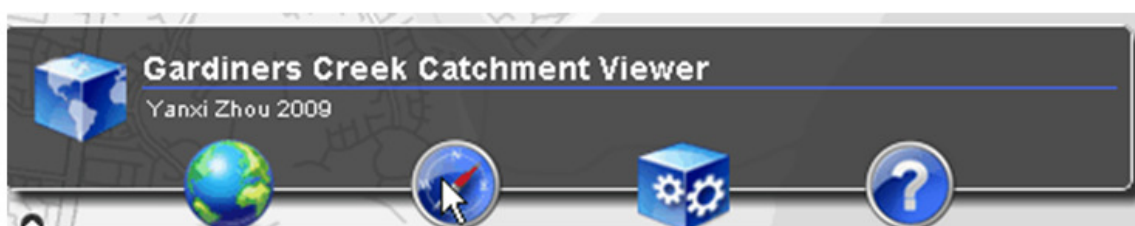


Figure 5-9 User Interface - title and main menu

Secondly, the map content and corresponding map services are defined with XML code. As shown in Figure 5-10, there are two base map services: the backdrop map and the aerial photos.

There are three live map data services (flood data, hydro data and contextual data) used in this application. Corresponding to the map services discussed in section 5.3.1, “<mapservice>” tags are used to refer to the map services running on the ArcGIS Server.

```
<map initialextent="2467111.62537115, 2386812.189654179, 2526378.4105713875, 2426499.769029338" fullextent="
2101353.502685 2286532.6599 2944369.300815 2835429.5623">
  <basemaps menu="menumap">
    <mapservice label="basemap" type="tiled" visible="true" alpha="1" icon="assets/images/icons/
i_globe.png">http://local/arcgis/rest/services/basemaps/basemap/mapserver</mapservice>
    <mapservice label="aerial photos" type="tiled" visible="false" alpha="1" icon="assets/image
s/i_globe.png">http://vrdwkews102/arcgis/rest/services/basemaps/arterialphoto/mapserver</mapservice>
  </basemaps>
  <livemaps>
    <mapservice label="links" type="dynamic" visible="false" alpha="1">http://localhost/arcgis/r
est/services/GC_catchment/flood/mapserver</mapservice>
    <mapservice label="intersections" type="dynamic" visible="false" alpha="1">http://localhost/
arcgis/rest/services/GC_catchment/contextual/mapserver</mapservice>
    <mapservice label="intersections" type="dynamic" visible="false" alpha="1">http://localhost/
arcgis/rest/services/GC_catchment/hydro/mapserver</mapservice>
  </livemaps>
</map>
```

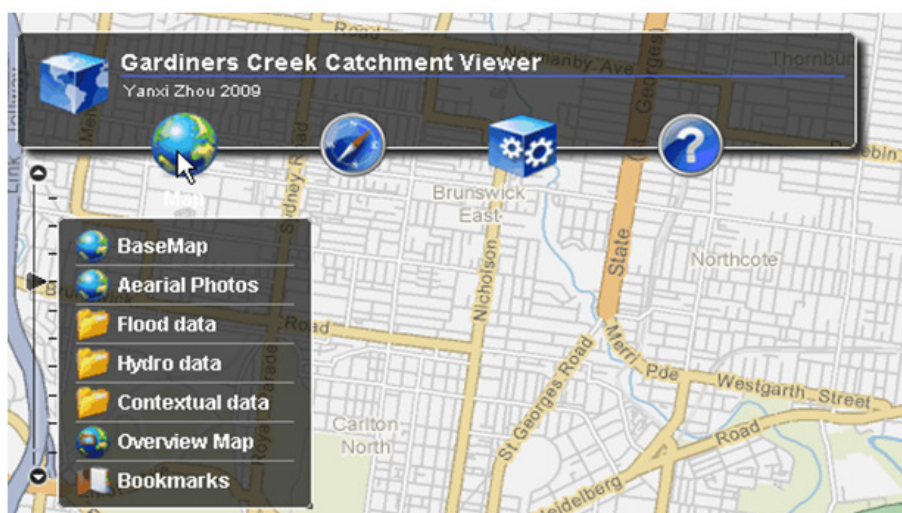


Figure 5-10 User Interface - tools

Lastly, tools and widgets are defined with XML code. As shown in Figure 5-11, navigation tools including zoom in/out, zoom to a full extent, pan the map are defined within the “<navtools>” XML tags; widgets such as locate features, select, buffer, overlay, draw, bookmarks and etc, are defined with the “<widget>” XML tags; Links to the user guide and the website are defined with the “Link” tags:


```

<navtools>
  <navtool label="zoom in" icon="assets/images/icons/i_zoomin.png" menu="menunav">zoomin</navtool>
  <navtool label="zoom out" icon="assets/images/icons/i_zoomout.png" menu="menunav">zoomout</navtool>
  <navtool label="full extent" icon="assets/images/icons/i_zoomfull.png" menu="menunav">zoomfull</navtool>
  <navtool label="move map" icon="assets/images/icons/i_pan.png" menu="menunav">pan</navtool>
</navtools>
<widgets>
  <widget label="Flood data" icon="assets/images/icons/i_folder.png" menu="menumap">com.esri.solutions.jsviewer
.widgets.livemapswidget</widget>
  <widget label="hydro data" icon="assets/images/icons/i_folder.png" menu="menumap">com.esri.solutions.jsviewer
.widgets.livemapswidget</widget>
  <widget label="contextual data" icon="assets/images/icons/i_folder.png" menu="menumap">com.esri.solutions.jsviewer.widgets.livemapswidget</widget>
  <widget label="overview map" icon="assets/images/icons/i_overview.png" menu="menumap" config="widgets/config/overviewwidget.json">com.esri.solutions.jsviewer.widgets.overviewwidget</widget>
  <widget label="bookmarks" icon="assets/images/icons/i_bookmark.png" menu="menumap" config="widgets/config/bookmarkwidget.json">com.esri.solutions.jsviewer.widgets.bookmarkwidget</widget>
  <widget label="search" icon="assets/images/icons/i_pushpin.png" menu="menuwidgets" config="widgets/config/locatewidget.json">com.esri.solutions.jsviewer.widgets.locatewidget</widget>
  <widget label="select" icon="assets/images/icons/i_search.png" menu="menuwidgets" config="widgets/config/searchwidget.json">com.esri.solutions.jsviewer.widgets.searchwidget</widget>
  <widget label="buffer" icon="assets/images/icons/i_pushpin.png" menu="menuwidgets" config="widgets/config/locatewidget.json">com.esri.solutions.jsviewer.widgets.locatewidget</widget>
  <widget label="overlay" icon="assets/images/icons/i_pushpin.png" menu="menuwidgets" config="widgets/config/locatewidget.json">com.esri.solutions.jsviewer.widgets.locatewidget</widget>
  <widget label="draw" icon="assets/images/icons/i_draw.png" menu="menuwidgets" config="widgets/config/drawwidget.json">com.esri.solutions.jsviewer.widgets.drawwidget</widget>
  <widget label="print map" icon="assets/images/icons/i_print.png" menu="menuwidgets">com.esri.solutions.jsviewer.widgets.printwidget</widget>
  <widget label="about" icon="assets/images/icons/i_about.png" menu="menuhelp" config="widgets/config/aboutwidget.xml">com.esri.solutions.jsviewer.widgets.aboutwidget</widget>
</widgets>
<links>
  <link label="help" icon="assets/images/icons/i_help.png" menu="menuhelp">userguide.htm</link>
  <link label="about us" icon="assets/images/icons/i_home.png" menu="menuhelp">http://www.rmit.edu.au</link>
</links>

```

Figure 5-11 XML code for defining tools and widgets in the User Interface

The development phase develops the tools and widgets. After the configuration phase is completed, the web page layout and the page components are set up for this application. However these tools and widgets are only registered as prototype objects in the config.xml, and the underpinning functionalities and business logic are yet to be implemented. In the development phase, the actual function for each tool and widget is developed using Javascript, dojo and ArcGIS API.

The development of widgets involves deployment of rather complex programming practice. The following steps are involved:

1. Create Dojo module and files for a new widget. Under 'JSViewer\js' folder, a new module folder is created for the new widgets to store the related files, then, based on the widget functionality and interface requirement, different files such as Javascript file, HTML template, icon image, i18n Support file (for supporting foreign language interface), are created in corresponding locations according to the predefined folder structure.
2. Define the widget template. In most scenarios, JavaScript Viewer Widgets have an HTML template that defines the look of the graphical user interface and the user behaviours when

interacting with the interface. A Widget may have a single panel or multiple panels, input boxes, drop down lists and other elements. All these components can be defined with in `<div class="widgetContent">` tags.

3. Implement the business logic. Once the widget interface is created, the user can interact with the GIS services via the widget. Interaction can include accessing a map, controlling navigations, displaying graphic data on a map, and receiving data from a map. These actions involve different services running on the ArcGIS Server, as well as the specific operation of the relevant business logic. To implement these business logic and functionalities, different functions and programs are created using JavaScript and Dojo.

As the output of the user interface development, the overall layout of the user interface with some of the widgets turned on is shown Figure 5-12. This user interface consists of four main menus– map, navigation, tools and help. Map menu includes all the map service widgets that allows users to interact with a map: turn on/off a map service and choose a certain layer within the map service to be turned on/off, overview map which shows the current map area within the full map extent, and bookmark function that saves favorite maps including map layers and extent. The navigation menu has the map control tools, such as zoom in/out, zoom to full extent, and pan the map. The tools menu has the tool widgets that the user can use to perform tasks, such as locate features based on the attribute selection criteria, select feature with graphic shapes (point, line, polygon), create buffer of selected feature(s), overlay a user-defined layer with selected feature(s), draw shape on the map, and print the current map. This user interface demonstrates some of the key spatial operations and analysis functionalities that can be developed in ArcGIS Server, and there is a great development potential for future extension with more advanced functions on top of this template.



Figure 5-12 User Interface

5.4. System architecture and sample outputs

5.4.1. Logical system architecture

Based on the discussion in previous chapters, the three-tier architecture, a client-server architecture widely used for web applications, has been adopted in this application. With three-tier architecture, the user interface, functional process logic, and data storage and data access components are developed and maintained as independent modules. Because the three tiers (i.e. the presentation tier, the business logic tier and the data/resources tier) can be implemented on separate platforms and can be upgraded or replaced independently when necessary, this architecture allows for a better system performance and more flexible system management.

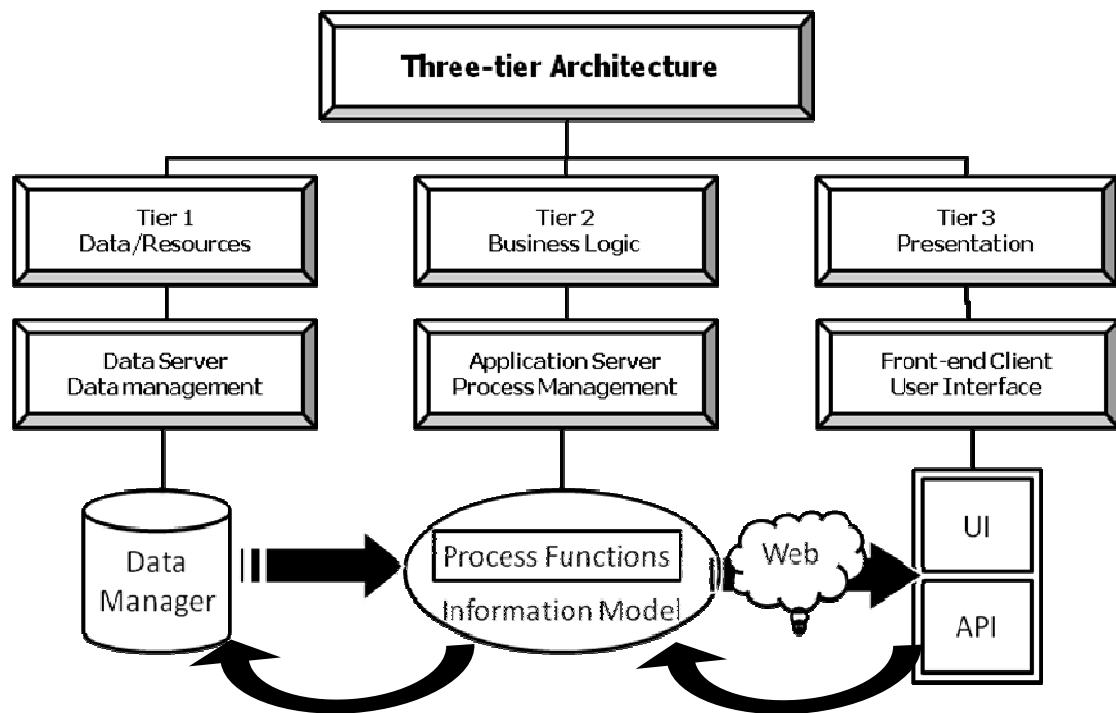


Figure 5-13 Logical system architecture

Figure 5-13 provides an overview of the system architecture, and illustrates the data flow process from storage to publication: the system is built on three key components. The data flows from one component to another in a circular order. The data/resources tier is the data management component, which stores data on a DBMS and manages data access. The business logic tier is the data process management component, which communicates with the other two tiers. This middle tier, as application server, receives requests from the presentation tier and applies the business logic to the data stored in the DBMS and then returns the processed results to the client. The presentation tier is the front-end client or user interface component, which interacts with users to get their requests and send these requests to the application server.

5.4.2. Physical system configuration

Based on the logical system architecture outlined above, the system has been developed on a platform consisting of Oracle Spatial 10g, ArcSDE, ArcGIS Server, IIS, Apache and Tomcat. Figure 5-14 shows the schematic representation of the basic system configuration of the developed web-based GIS system.

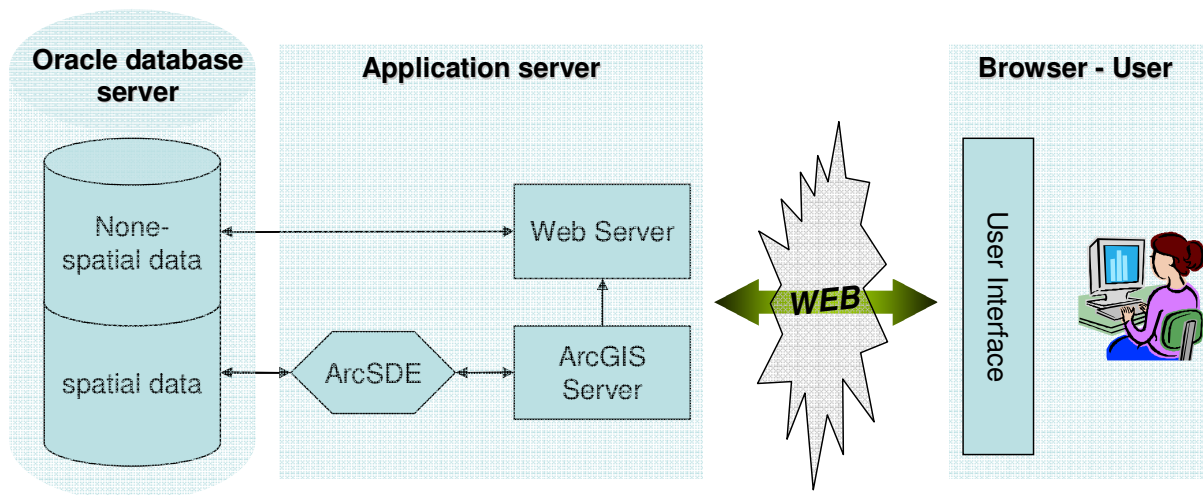


Figure 5-14 Physical system configuration

The system consists of three main components, corresponding to the three-tier architecture: the data tier is developed with Oracle Spatial 10g; the application tier is built with IIS, Apache and Tomcat as a web server, and the ArcGIS Server combined with ArcSDE as a spatial application server; and the presentation tier is developed using programming languages such as XML, javascript, dojo and ArcGIS Server API.

At the data server, the DBMS (residing in different servers) is developed using Oracle Spatial 10g, and the data were stored as SDO, which is an efficient format for both raster and vector GIS data types. At the application server, the system provides seamless integration of web server, ArcGIS Server and business logic. The application server consists of two parts: web server and ArcGIS Server. The web server is configured with IIS, Apache and Tomcat, which handles requests and responses from the user end via a web browser, then the process sends the interpreted requests to the ArcGIS Server. The ArcGIS Server allocates the request to the related GIS services, then processes the request and sends the result back to web server. Finally, the web server delivers the output to the user via the user interface. ArcSDE is used in this middle tier to coordinate between ArcGIS Server and Oracle database. At the user end, a user-friendly interface has been developed to allow the user to manipulate the map, perform tasks with different tool widgets and interact with ArcGIS Server. SampleJavascriptViewer configured with XML is used as a base template, and based on the user needs a set of widgets are developed with Javascript, dojo and ArcGIS Server API.

5.4.3. Sample outputs

Equipped with a number of GIS services created and different widgets developed to consume these services, the web-based GIS prototype now supports four main categories of query and reporting functionalities: interactive content control and map navigation, feature based query and reporting, attribute based query and reporting, and spatial query and reporting.

In the interactive map contents control and map navigation application, spatial data is represented as geographical maps. The user can control the map composition interactively with customised tools to get their desired map contents at a preferred map scale. As shown in the image on the left of Figure 5-15, users can select from the map menu to decide which map theme(s) is/are to be displayed on the map. Within a map theme, the user can also control which map layer(s) are to be turned on/off by selecting the layers in the TOC (Table of Content) of the corresponding map theme widget. This functionality allows users to control the map content and access the required spatial information. The right picture in Figure 5-15 shows the key map navigation tools, which allows user to zoom in/out, zoom to full extent which is the Gardiner Creek Catchment area, and to pan the map. Instead of using the zoom in and zoom out tools, users can also utilise the scale bar to control the map scale. This is located at the left side of the screen. Mouse movement and actions are also supported in this application in map navigation control: double click on the left key of the mouse to zoom, double click on the right key of the mouse to zoom out, and press the left key down which dragging the mouse so as to pan the map. These map navigation tools allow users to control the map scale and extent for accessing the map area of interest.

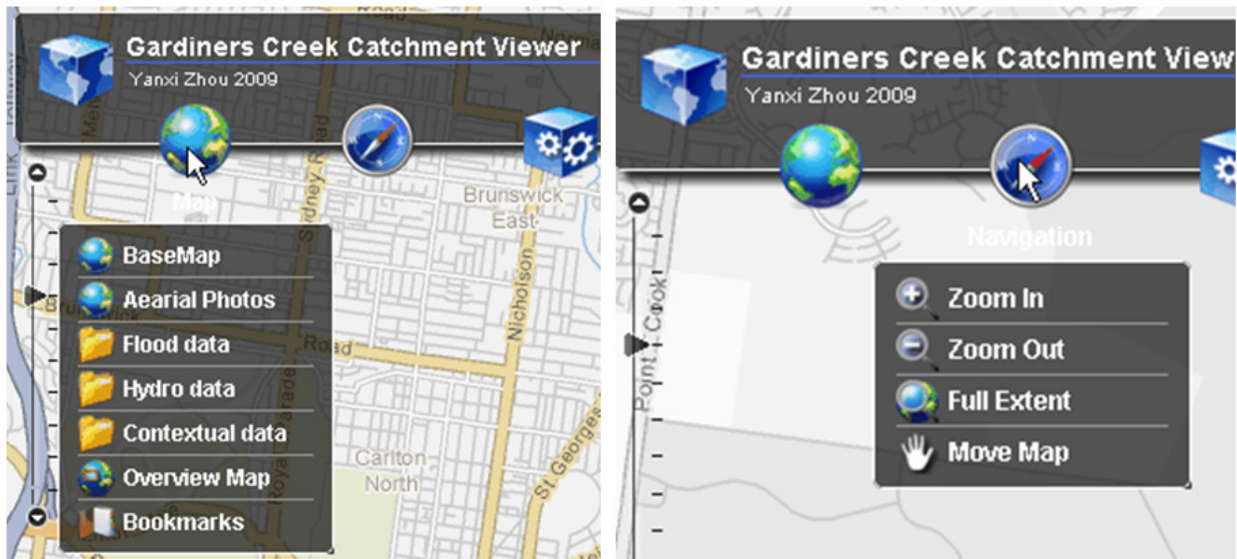


Figure 5-15 A schematic plot of interactive maps

Feature based query and reporting tools provide an essential way for spatial data access, query and reporting and allow users to retrieve attribute information of the spatial features in the map based on the geographical location of feature. The feature based query and reporting tools include identifying feature(s) and selecting feature(s) etc. As an example, the select tool shown below allows users to select features in the map and get the attribute data of the selected feature. Figure 5-16 shows the user interface of the select tool. Since there are multiple layers in the map, the user needs to first choose which feature layer the select action will operate, and then they need to choose what shape to be used to select the features. The shape can be point, line, rectangle, or a user-defined polygon. In this demonstration case, a rectangle shape is used to select the utility points in the map. As shown in the left picture in Figure 5-17, the utility points within the rectangle are identified by highlight cyan in the map, and the attribute data of these points are displayed in the select tool widget window, as shown in the right picture of Figure 5-17. For reporting purposes, the user can click on the “Export Data” button to save the selection results as a file on their local hard disk in txt, xls or dbf format.

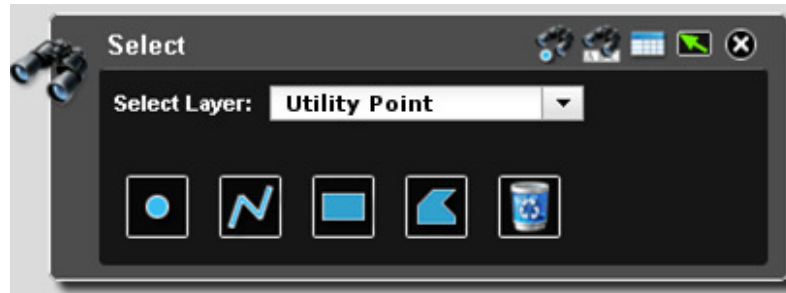


Figure 5-16 Select tool interface

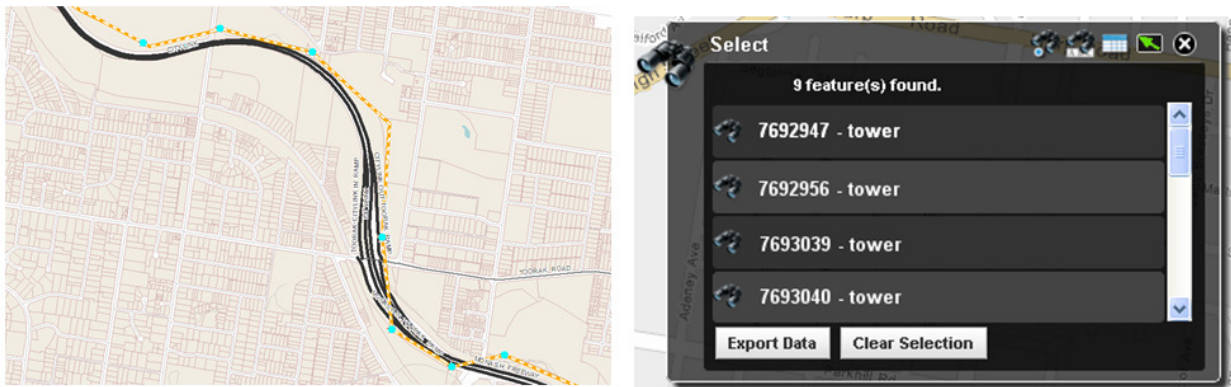


Figure 5-17 Select tool output

Attribute based query and reporting tools allow the user to get spatial feature(s) based on the attribute data. A search tool has been developed in this application based on the ad hoc query and reporting concept. Figure 5-18 shows the user interface of the search tool. After the user selects a feature layer to search, the attribute fields of the selected layer will be automatically populated by programming scripts with some definition rules. With an ad hoc query method, users can choose to input the full selection criteria or input selective information to conduct the search. Moreover, some intelligent functions have been built to automatically filter the field values. For example, after user selected “Chadstone” as the suburb, the road name field will be automatically filled with the roads within that suburb. If the user inputs a road name that doesn’t exist in that suburb, an error message will be automatically displayed. This robust filter function will facilitate the search function by reducing human operational errors. Once the user clicks on the search button, the spatial feature(s) matching the selection criteria will be selected and highlighted, and the map will automatically zoom to these feature(s) as shown in the left picture in Figure 5-19. At the same time, all the attribute data of these matching features will be

displayed in the widget window (shown in the right picture in Figure 5-19). The attribute data can be exported into local files in different formats. Overall, attribute based querying and reporting tools allow users to access, query, retrieve and report both spatial and attribute data from the database based on user defined selection criteria.

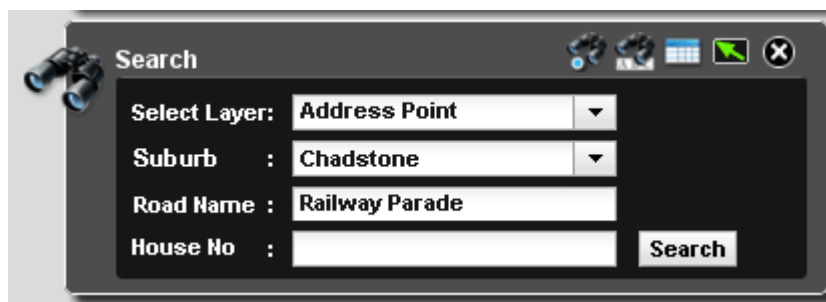


Figure 5-18 Search tool interface

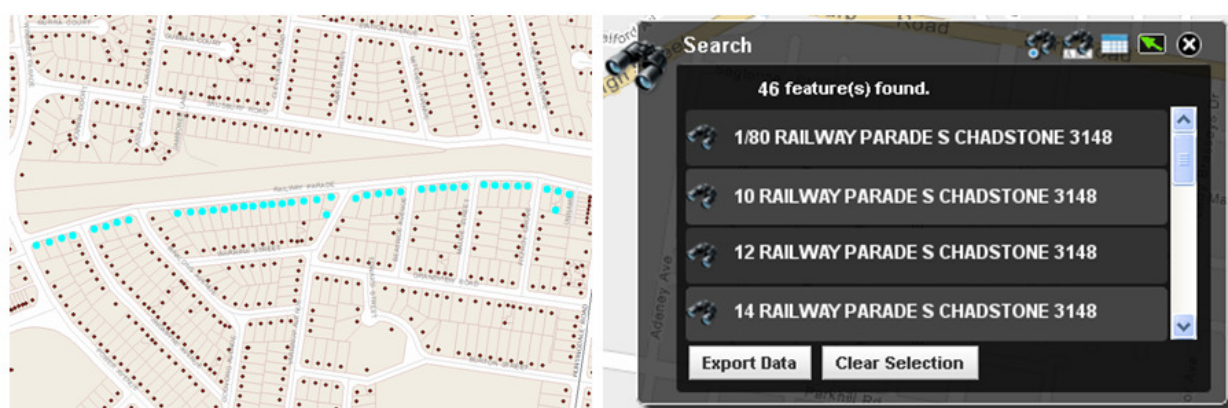


Figure 5-19 Select tool output

Spatial query and reporting – spatial query and reporting tools allow users to retrieve data based on the spatial relationships between spatial features. As addressed in previous chapters, there are many different spatial relationships (e.g. contain, intersect, overlay, within a buffer distance and so on). Since all feature layers in the map can be topologically related, the operations based on the spatial relationships are very important for location based analysis and data retrieving. As shown in Figure 5-20, for examples, a spatial query to overlay a 100-year flood extent with the property feature layer is conducted to display all the properties affected by the flooding event. User can visually inspect the affected properties on the map or generate a report on the searching results.

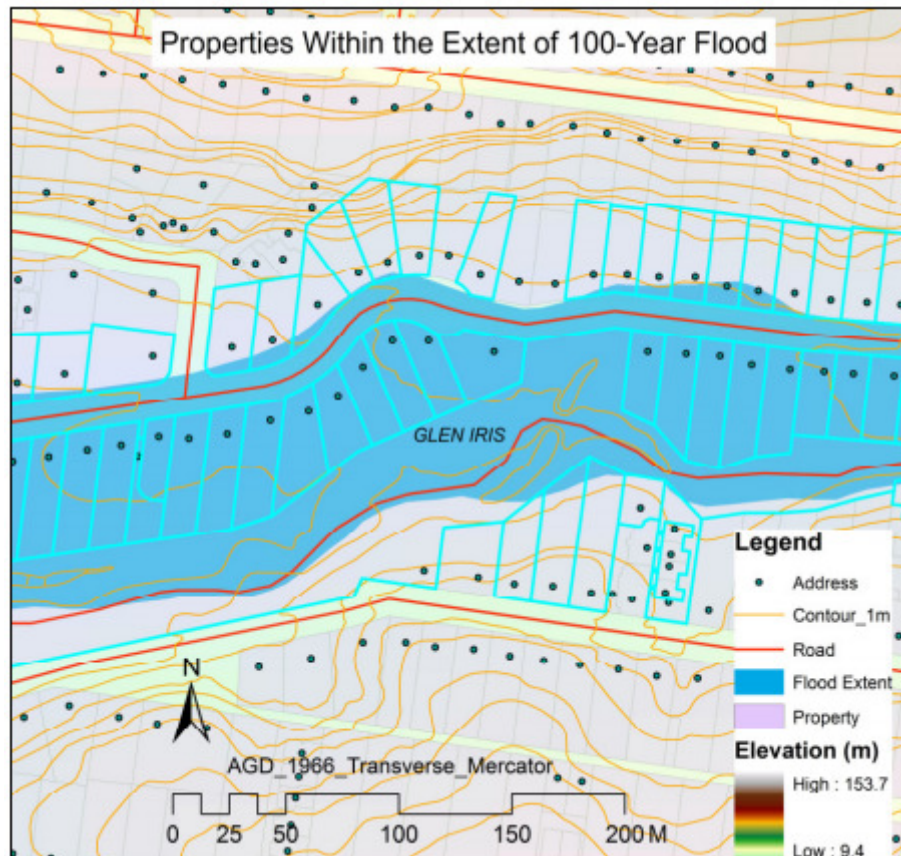


Figure 5-20 Spatial overlay

5.5 Summary

This chapter presents the work conducted in the case study. In section 5.1, the study area and the source datasets are introduced. Data organization and database development are then described in section 5.2. User interface development is discussed in section 5.3, and the overall system architecture with a detailed discussion on system components and some sample outputs of the prototype system are presented in section 5.4.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Emergency management

Natural disasters impact upon many aspects of human society, and emergency management involves many parties. They include government agencies, non-government organizations, research institutes, and local communities. Collaboration is called for in all aspects of emergency management to mitigate and reduce the impacts. Effective collaboration in emergency management calls for efficient information sharing which in turn depends on appropriate information system design and implementation.

From comprehensive review, it is clear that there is a paradigm shift occurring in the thinking and practice of emergency management: from reactive emergency response to proactive risk mitigation. This study also found that rapid developments in information and communication technologies have brought about both challenges and opportunities to the disaster mitigation and emergency management communities. The claim that more information leads to better decision-making can only be sustained when and where the information is properly collected, made accessible on demand, presented in a the usable format, and used correctly by users.

Participants involved in different activities have different information needs in terms of datasets, data formats, access methods, and tools for analysis. In support of the many different parties involved in different activities associated with the overlapping stages in a typical disaster emergency management cycle (e.g. prevention/mitigation, preparedness, response and recovery), access to information on the spatial, temporal, and thematic aspects of hazards, exposure and the vulnerability of elements at risk is indispensable, if procedures for evaluation of baseline situations, risks, impacts and scenarios are to be established.

Given these considerations, this study aimed at the development of a technological platform to facilitate information sharing for mitigating risks associated with flood hazards. The thesis starts with the identification of user groups and their information needs, and emphasizes that these should be taken into account in the early stage of information system design and that it is

important to address user needs, however different, through adoption of appropriate data modeling, database design and system development / implementation.

From analysis of emergency management of user groups and their information needs, the key challenges for disasters information management and sharing have been identified. Accordingly, the research efforts have been directed toward the following research questions emerge:

- 1) How to properly represent disaster events in both space and time domains?
- 2) How to establish timely and robust data access?
- 3) How to develop a reliable and flexible user interface to facilitate effective information querying, reporting and sharing?

6.2 Representing natural disasters and managing the data

Natural disasters are dynamic and episodic events. A range of natural hazards, environments and impacts must be represented if emergency management models are to be useful.

To be useful, in support of either proactive risk mitigation efforts (such that the interaction between the hazards and the elements at risk can be avoided) or reactive emergency responses (such that unavoidable interactions must be dealt with), the data designed for decision support must include spatial, temporal and thematic elements. These representations, in the form of datasets, need be logically organized and stored, and then made readily accessible, flexibly retrievable and widely sharable. In exemplification, representation of flood-induced disaster events and their impacts, and the techniques for database assembly, management and deployment is developed in this study.

Choice of data model is crucial. Accordingly, a comprehensive review on the history of GIS data model evolution in the past fifty years was undertaken. Three popular data model type used in GIS communities have been identified: geo-relational data models, object-oriented data models, and object-relational data models. Assessment of the characteristics, components, advantages and disadvantages of these data models allows their suitability for the intended flood-related applications to be identified. Examination of key approaches of spatio-temporal data modelling, including snapshots method, event-based data model and object-event data

model, found that the conflict between discrete nature of a database and the continuous feature of dynamic disaster events continues to challenge those intent on spatio-temporal data modelling in GIS and deployment of GIS for decision support in emergency management. From appraisal of current data models and user needs, it is argued that the object-relational data model best represents flooding disaster events. Both logical and physical data models for three thematic data collections, including flood data, hydrographical data and contextual data, have been developed. For efficient data management, especially spatial data management, these data collections are organised with a object-relational database design and implemented with RDBMS including Oracle Spatial and ArcSDE.

6.3 Web-based data access

Web-based data access strategies are selected for data and information sharing among stakeholders. From a user perspective, a web-based system is easy-to-use and flexible, especially for public participation. With a standard browser-based interface, information can be easily accessed by world wide users across different computer platforms. From a system perspective, a web-based system allows information to be managed and shared by different parties via the computer network. Currently, this is the most efficient platform for information sharing and management among many parties. This is also considered to be a good data and model sharing solution for facilitating public participation in decision-making.

Reliable and robust information access can only be achieved by applying suitable information query and query optimizing techniques. Database with proper indexes and optimized query design perform much faster than those not so endowed. This is critical in enterprise GIS database design. This study addresses the related issues, techniques and implemented these techniques in the case study.

User interface design and report function development are the two key aspects that have the most influence on the effectiveness and efficiency in information sharing among users. . The study found that the best user interface design is the one most suitable (not necessary the most advanced) for addressing the focus user group needs (information needs and system needs). It is Ad Hoc reporting strategies that provide great flexibility for users intent on customizing their

reports according to their particular needs. This feature of the developed prototype is well-received by its trial users.

6.4 A prototype of web-based information sharing

A prototype of the object-relational database management and compatible web-based information sharing system has been developed in this study, using source datasets describing flood events that occurred in the Gardiner Creek catchment and documenting associated hydrological and other geographical contexts. The prototype system has a three-tier architecture including database server tier, data engine tier and application server tier. The web-based platform enables distributed, interactive data accessing, querying and reporting supports, and therefore supports efficient and effective information sharing.

The prototype is implemented with the following procedures:

- 1) First, a detailed physical data model based on the logical data model and available datasets was created, and then procedures to upload data and optimize database performance, such as creating tables, schemas, spatial and attribute indexes, were carried out.
- 2) Secondly, ArcSDE has been specially configured to transfer data from Oracle to ArcGIS Server, and different GIS services including map services, image service, geometry services and geoprocessing services were published on ArcGIS Server to serve map generation requests and query and reporting operation requests from the user.
- 3) Finally, a Sample JavaScript Viewer template developed by ESRI has been adapted to deliver the user interface. Programming languages such as XML, JavaScript, dojo and ArcGIS Server API are used to customize the web page layout and build new widgets that allow user to conduct different queries and generate reports.

Sample outputs includes the user interface overlook, feature-based query and reporting interface and outputs, attribute-based query and reporting interface and outputs, and spatial query and reporting outcomes.

6.5 Conclusions and recommendations

To conclude, this study examined the information needs for risk mitigation, investigated issues and techniques related to the representation, organization and sharing of disaster information, and developed a web-based GIS prototype, using flood information as a case study.

This research was designed to develop a comprehensive framework and implementation of a robust practical prototype system for disaster data management by applying the state-of-the-art GIS, database and web 2.0 technologies.

System and user needs analysis is fundamental in all information system developments. Interview and literature review methods were used for identifying system and user needs at the early study stage. However, information in the literatures is comparatively general, and of limited value for guiding a specific case study, focusing on flooding of one particular catchment. Stakeholder interviews are the key to customization of theory to practice time-consuming. effective analysis in user needs calls for close collaboration with as many stakeholders as possible. It would be useful if the developers can observe the users' routine works and work closely with the users while identifying the scope for upgrading the decision support system.

Data availability, quality and uncertainty will cause problems in any GIS system, the more so for the researcher calling for timely data access from the same system. Data set access may be restricted or limited due to many reasons. Disaster information (flooding in this case) is difficult to collect and so is not well monitored in Australia. In this study, the researcher only has an access to the modelled flood extent and stage data (used to define 50-year and 100-year levels), and discontinuous water level data. It was found that the data sets, which were from different sources, exhibited a range of qualities, especially regarding accuracy and consistency. Accordingly, data processing was time consuming. However, developers should prepare for these problems and difficulties in all such applications. On the other hand, the study outcomes can be guidance for the future data collection and for consensus building among stakeholders with regard to metadata standards.

The biggest challenge in this study is the spatio-temporal representation of flooding and related phenomena in the database system. The functionality of current GIS and database systems is not

ideal for representing and handling the highly dynamic natural phenomena. It is a challenge to integrate the temporal dimension into the record-based database in a way that incorporates spatial features. Chapter Three explored the key data models for spatio-temporal representation. A timestamp-based data model was designed in this study.

Small datasets (for one catchment) were used in this database system. When it comes to real application, the system will host a large amount of data and services for different users. Such a disaster database system will be used by many departments. The study considered database query optimization by using spatial indexing techniques (R-tree). The optimization and indexing strategies need to be re-studied on more complicated and larger voluminous data. Database turning and optimizing is complex and requires professional knowledge. This will be one of the highest priority tasks in real applications.

The developed prototype system demonstrated some key GIS operation and analysis functions (Chapter Five). Many tasks involved advanced spatial, temporal and spatio-temporal analyses. The prototype is shown to serve well for demonstration purposes. The genuine user interface design needs to be re-designed for each user group that adopts the approach exemplified in this study.

This research does not take into account the operational need for system security and user access rights. This is important in any information sharing system. Data safety and system reliability are critical considerations each level of user, i.e. data collectors, database managers, and end-users. Proper plans need to be developed for system security and user access. Moreover, the system did not consider the complexity of accessing system platforms. The system was developed on two locally connected MS Windows XP systems. Testing has not been taken on other computing devices (i.e. mobile) and operating systems (i.e. UNIX). Some browser incompatibility problems have been found on different Internet browsers such as IE 7 and IE 8, FireFox 2 and FireFox 3, and Google Chrome 2. The application is not functional in all browsers at the moment, and further web development is needed to fix these issues.

Web 2.0 brings great potential to the Web-based GIS. Researchers and developers should be ready to take the challenges and opportunities offered by web 2.0. Web 2.0 will offer much robust network and computing power exploitable by many GIS systems. Transferring huge and

complicated GIS data will be not an issue for the next generation Internet. More and more users will be able to access numerical data sets simultaneously. Furthermore, Web 2.0 will introduce an advanced interactive interface for users and provides dynamic and advanced operations via the Internet. Users, including the public, can contribute to the data collection, data management, data analysis, and consequently the decision-making process.

Emergency management starts before the disaster strikes. Effective risk mitigation and emergency response calls for reliable, comprehensive and timely information supports. The prototype developed in this study provides a technological solution to this call and can be adapted into emergency management applications, including flood emergencies. But the real challenge to meet this call for information support requires essential human-centric elements which are beyond the purely technological solutions.

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